STABILIZED RETINAL IMAGE PHENOMENA
and their Theoretical Implications, approached through a systematic study of Foveal Linear Flash After-images.

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PREFACE

My interest in this particular area of perception was fired by Barlow's (1963) paper on contact lens slippage, which challenged the validity of many previous findings using the technique, and initiated the idea that flash after-imagery would be a suitable avenue of approach to ensuring the complete stabilization of a retinal image. This new approach, however, is not without its limitations and difficulties, especially as to the relationship of the resulting phenomena to those found using continuously stabilized, invariant visual input. The area also fitted well into an undergraduate interest in subthreshold perception (Hall, 1964), because the fragmentary perception of visual stimuli at threshold levels is somewhat analogous to the reported fragmentation of stabilized retinal images.

The critical review chapters encompass all the literature that was thought to be relevant to the area of study (up to March 1967), detailed evaluation being made of those aspects which were considered to be of primary consequence (a review of the literature from April 1967 to June 1969 may be found in the Appendices, Section 10.11). As this study entailed the development of a rather novel complex of apparatus, together with the evolution of a viable design and procedure, the size of the investigation may seem to be rather more contracted than what can be achieved using existing apparatus and established procedures, but this is one of the almost inevitable consequences of advancing on a relatively unexplored front. Raw data has not been incorporated in the thesis, as its inclusion would have resulted in a very cumbersome volume, but sufficiently detailed results are tabulated so that alternative interpretations may be made of the more equivocal findings. In order to impose some form of uniformity on the diversity of units found in photometry, the photometric measurements mentioned in the text are converted to metric units where necessary (these units having been adopted by the C.I.E.); but, for completeness, these are preceded by values in the units used in the original measurements. The bulk of the experimental work and writing in this thesis were performed at Edinburgh University Psychology Department between October 1964 and August 1967, but the two experiments mentioned in Sections 10.8. and 10.9. and the review of Section 10.11. were performed at Leeds University Psychology Department between September 1967 and July 1969.

This thesis is presented as a twofold approach to a specific set of topics requiring both empirical procedures and a wider theoretical discussion, thus resulting in specific empirical data being viewed in the context of certain visual psycho-physiological theories and hypotheses.

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1. INTRODUCTION

For more than a decade, there has been considerable interest shown in images, stabilized with respect to the retina, and in the implications of findings in this area to our understanding of the basis of the psycho-physiology of vision. Superficially, some of the findings are in direct conflict with others, especially as to the perceptual effects of stabilizing an image relative to the retina, and it was these discrepancies which sustained interest in this study. In order to put the phenomena into perspective, it is first necessary to consider some relevant visual physiology.

1.1. Involuntary Eye Movements

Even under conditions of steady fixation, small involuntary movements of the eye are present (physiological nystagmus). Under normal conditions, therefore, an image on the retina is constantly shifting over its surface. Three types of movement are usually described: (a) a slow drift of the eye away from the fixation point, this being due to an instability in the oculomotor system (Ditchburn, 1955; Cornsweet, 1956); (b) a rapid "flick" or saccade, which seems to compensate for the slow drift by returning the eye back towards the fixation point (Cornsweet, 1956; Nachmias, 1959); and (c) a high frequency tremor, which is superimposed on the drift.

The parameters of these movements vary somewhat according to different measuring techniques and individual differences. However, critiques of the various methods are given by Riggs, Armington and Ratliff (1954) and Alpern (1962), and a historical summary of the actual findings up to 1948 is given by Ratliff and Riggs (1950), while the more recent findings are tabulated by Ditchburn and Ginsborg (1953, page 13). As the reported results of Ditchburn and Ginsborg (1953) and Ditchburn (1955) give the most comprehensive account of the actual parameters of these eye-movements (most of the findings being in accord with other researchers, in so far as they cover the same ground), they are listed below in summary form:

(a) "<u>Slow drifts</u> of up to 5 minutes of arc (for each rotation) occurring in the interflick periods" - having a mean duration of approximately one second and an angular velocity of roughly one minute of arc per second.

(b) "<u>Flicks</u> occurring irregularly at intervals varying from 0.03 second to 5.0 seconds. The amplitude of flicks for the H & V* rotations ranges from 1 - 20 minutes of arc. For the T* rotations the flicks are very small, usually about 2 minutes of arc." The mean amplitude for H & V rotations is approximately 6 minutes of arc, with a mean duration of 0.025 second, the velocity being of the order of 10°/second.

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* H - horizontal; V - vertical; T - torsional.

(c) "<u>Tremor</u> of frequency 30 - 80 c.p.s. The amplitude of this tremor is 5 - 15 seconds of arc for H & V rotation and up to 45 seconds of arc for the T rotation.... The maximum angular velocity during the tremor movements is about 20 minutes of arc per second."

It is worth pointing out that in binocular vision, although the involuntary drifts and corrective flicks of the two eyes are closely synchronised, the small tremor movements are independent (Riggs and Ratliff, 1951): thus "the 'corresponding' points of binocular vision represent corresponding mean locations on the retina, rather than a one to one correspondence between cone receptors in the two eyes" (page 17).

According to Ditchburn (1955), the total effect of the drifts and flicks operating together for a fixation period of about two seconds, is to make the image of a point object wander around a small region in the centre of the retina, subtending an angle of about 10 minutes of arc. Over longer periods of time, a circle subtending an angle of about 20 minutes of arc would be required to encompass these movements.

Reviewers of stabilized retinal image phenomena, such as as Heckenmueller (1965) indicate that the questions which experimentation in this area have attempted to answer are: "(a) What are the nature and extent of these involuntary eye-movements? (b) What effect do these movements have on the visual process?"

The first question has in the main been answered, and we are left with the second, which will be preceded by a detailed survey and evaluation of the various techniques that have been used to stabilize images on the retina. The consequences of stabilization will then be considered, and in this chapter an attempt will be made to provide an answer to some facets of the second question. Certain of the remaining aspects will then be portrayed as requiring further investigation, and these will be studied and analysed in the remaining chapters.

1.2. Resume

Even when fixating an object, its image is shifting over the surface of the retina due to involuntary movements of the eye, which can be classified as follows: a slow drift away from the fixation point, a rapid flick which returns the eye back towards the fixation point and a high frequency tremor which is superimposed on the drift.

2. TECHNIQUES OF RETINAL IMAGE STABILIZATION

2.1. Imaging of Internal Ocular Structures

2.2. Optical Lever Systems

2.3. Ocular Target Attachments

2.3.1. Contact lens slippage

2.4. Flash After-imagery

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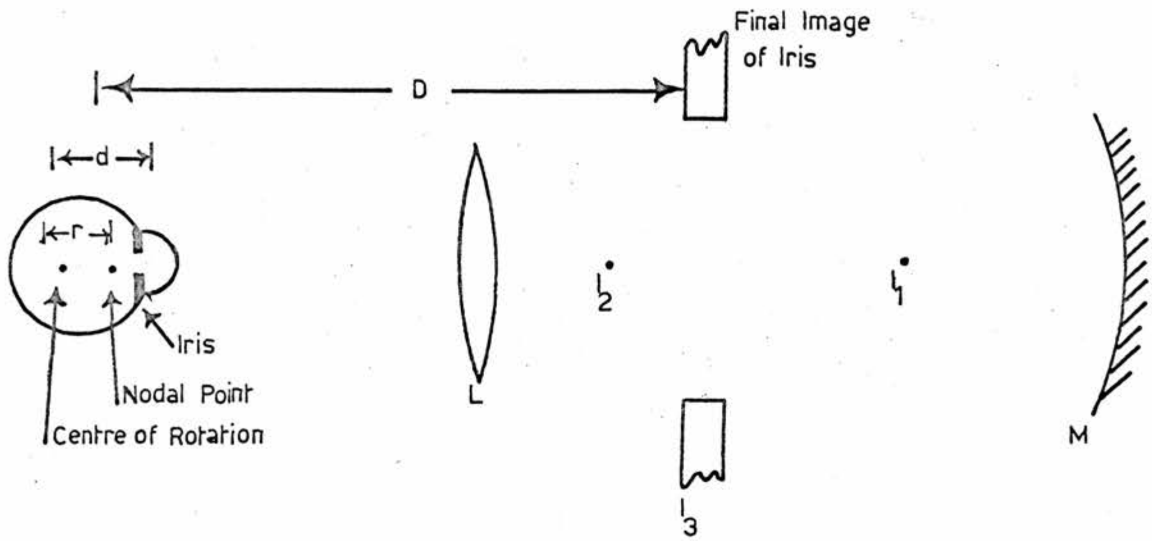


Diagram 2.i. Apparatus for stabilizing a retinal image of the iris: Ditchburn, Fender, Mayne and Pritchard (1955), page 1165. The lens L forms a real magnified image of the iris at I_1, the concave mirror M forms a further magnified real image of I_1 at I_2. The subject sees a virtual image of I_2 formed at I_3 by the light on its second transit through the lens. It can be shown that the magnification 'M' needed for stabilization is given by 'M' = (D + r)/d where D is the distance from the nodal point of the eye to the image of the iris, d the distance from the centre of rotation of the eyeball to the iris and r the distance between the centre of rotation and the nodal point.

2. THE TECHNIQUES OF RETINAL IMAGE STABILIZATION

In order to stabilize an image on the retina, one must present the visual stimulus so that its position, relative to the retina, is the same irrespective of any movement of the eye, the visual stimulus moving with a direction and magnitude precisely opposite to that of the eye movements. It is perhaps worth noting that the steady fixation of an object in the peripheral visual field results in its disappearance after a few seconds (Troxler's Effect), this phenomena having been extensively studied by Clarke (1960, 1961, 1962). However, the techniques developed to achieve central retinal image stabilization can be classified into four main groups: (1) imaging of internal ocular structures, (2) optical lever systems, (3) ocular target attachments and (4) flash after-imagery. The various aspects, advantages and limitations of these techniques will now be considered.

2.1. Imaging of Internal Ocular Structures

This technique utilizes some part of the structure of the eye as the image, which therefore remains stationary relative to the retina. Ditchburn, Fender, Mayne and Pritchard (1956) developed a simple monocular lens/mirror system (Diagram 2.i.) by means of which a subject could see an image of his iris. The magnification of the system was such that the image of the iris made the same angular movement as the eye itself, and thus the image of the iris on the retina was stabilized, so long as the subject did not move his head. His head was, therefore, firmly fixed and aligned so that the iris lay on the optic axis of the system: the latter requirement was crucial as a misalignment of only 1 m.m. would move the image about 25 m.m. off axis. When demonstrated at the Physical Society Exhibition in May, 1956, only about fifty per cent of the subjects were able to 'find the image', due to this crucial adjustment.

Ratliff (1958) has shown that simply by looking through a polarizer at a field of blue light, one can obtain an image of 'Haidinger's brushes', which are dark and shaped like an hour-glass. Being entoptic structures, they are therefore stationary, relative to the retina, and the resulting image is stabilized. Helmholtz first suggested what caused these images to appear, and this interpretation is now generally accepted. Certain of the molecules in the macula lutea (a yellow, heavily pigmented area surrounding the central fovea) are oriented with radial symmetry about the fovea, and more light is absorbed by those molecules that are parallel with the plane of polarization, than those oriented in other directions. The orientation of these 'brushes' is a function of the relative orientation of the polarizer in front of the eye, and the analyser (the molecules of macula lutea) within the eye. When the outer polarizer is fixed, then the orientation of the brushes will change only when the eye performs torsional rotation. The brushes will, therefore,

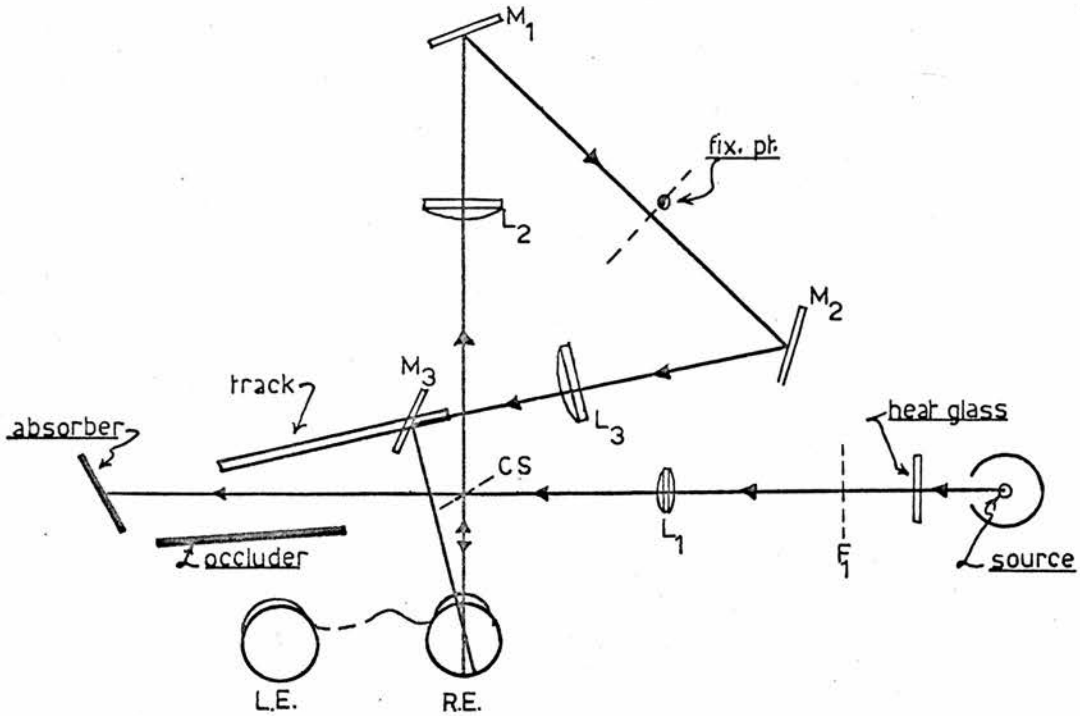


Diagram 2.ii. A stabilizing system requiring no attachments to the eye: Cornsweet (1962, page 654). The glass cover slip CS reflects about 10% of the light rays and transmits the remaining 90%. F_1 is the position of a square aperture, the fixation point (fix. pt.) only being used during the adjustment of the apparatus.

remain stable as long as there are no large, oblique movements of the eye, i.e. only during fixation.

Campbell and Robson (1961) have developed techniques for observing the two well known entoptic shadows of the retinal blood capillaries and the macular pigment. If a small bright beam (of less than 0.2 m.m.) from the face of a cathode ray oscillocope is moved at a certain amplitude and frequency in the pupil plane, then a highly detailed shadow of the retinal capillaries is seen. To overcome the fact that these shadows cannot be cast centrally, they made observations on the shadow of the yellow macular pigment, which was produced by flickering alternately, a green and purple light beam, equated in brightness, at suitable frequencies. When this beam was brought to a narrow focus in the pupil plane, some subjects were able to detect very fine, discrete mottling in the centre of the field of vision, the shadow of the macula pigment also being visible.

Cornsweet (1962) describes in detail a relatively simple optical system, which presents the subject with a stabilized real image of a part of his peripheral retinal structure, without attachments to his eye (Diagram 2.ii.). Using the reflectance/transmission characteristics of a piece of glass (CS) set at an angle of 45° to the optical axis of the system, the image of a small square of light is formed by L_1 on a part of the peripheral retina, and a very small fraction of the light striking this is reflected back out of the eye, along its entry path and through the CS. An image of the retinal structure, within the illuminated square of the peripheral retina, is then formed from these reflected rays, by a system of lenses and mirrors (L_2, M_1, M_2, L_3 and M_3), on the central retina. The system is arranged to have a magnification of x 1.0, and any movement of the eye will produce an exactly equal shift of the retinal image of the retinal structure, and is effectively stabilized for all possible movements of the eye. The device also stabilizes the image against translational movements of the head and eyeball, but the image of the square of light is not stabilized against rotational or torsional movements.

The above variations of the ocular structure technique have the advantage that the images so produced are usually highly stable: the stabilized image produced by Cornsweet's system being the most satisfactory, as it is compensated against translational head movements, while the other techniques require that the eye-movements should be relatively small and that the head movements be constrained. They are also free from distortions (to be discussed later), which are produced by techniques using attachments to the eye. The serious disadvantage of the method of imaging internal ocular structures on the retina is that one is limited solely to these structures for one's stimuli, and it is usually not possible to vary the degree of stabilization.

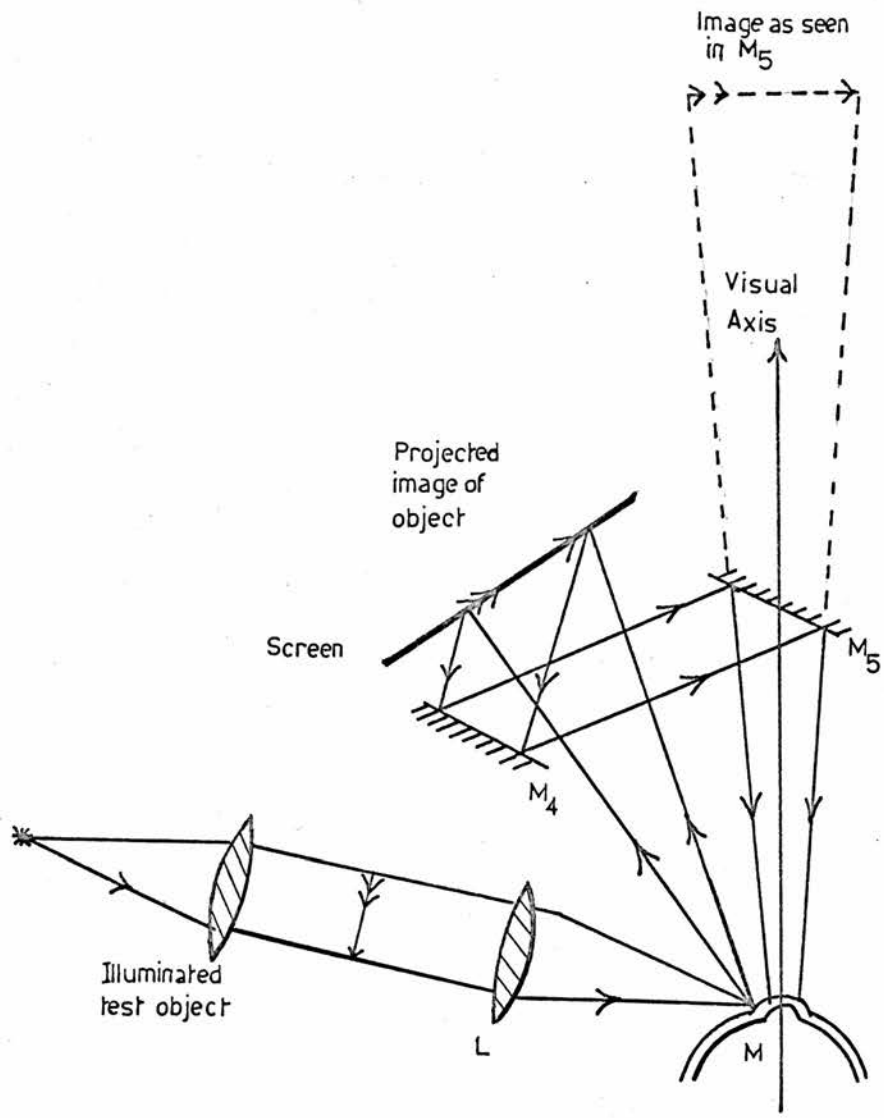
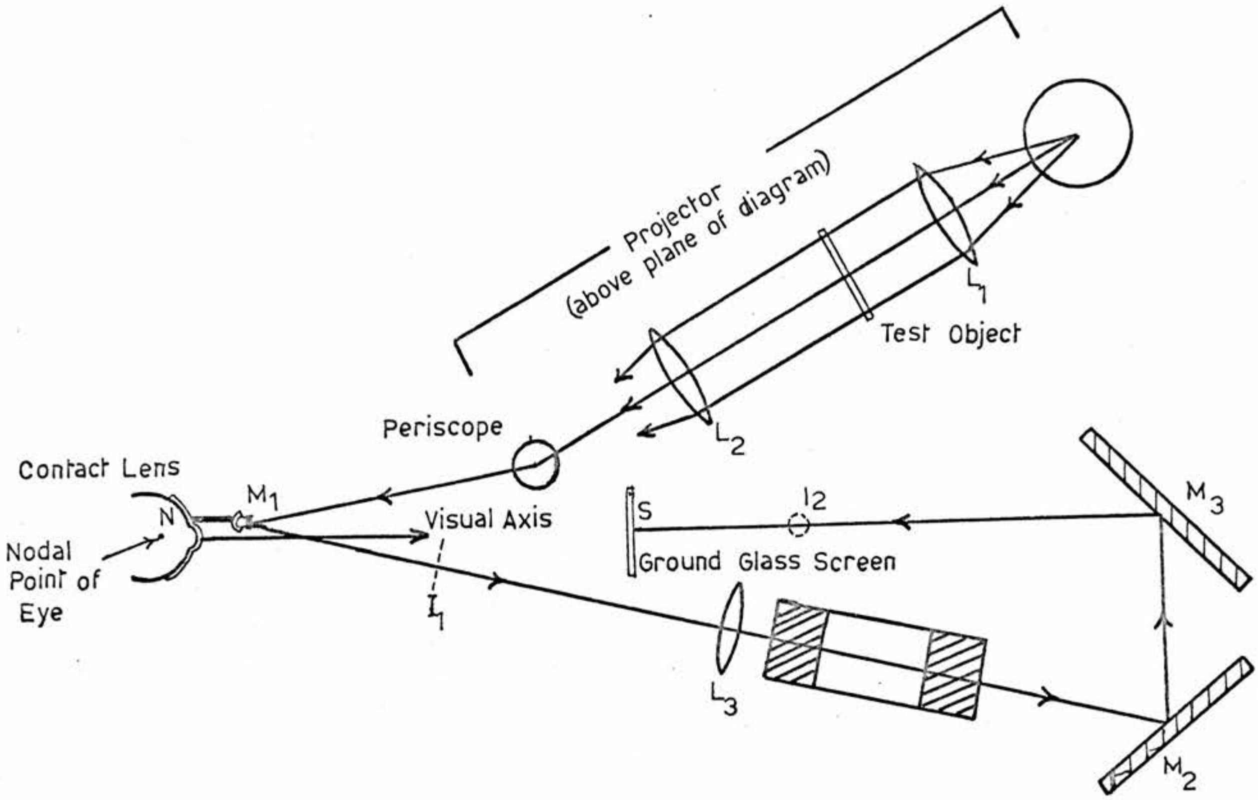


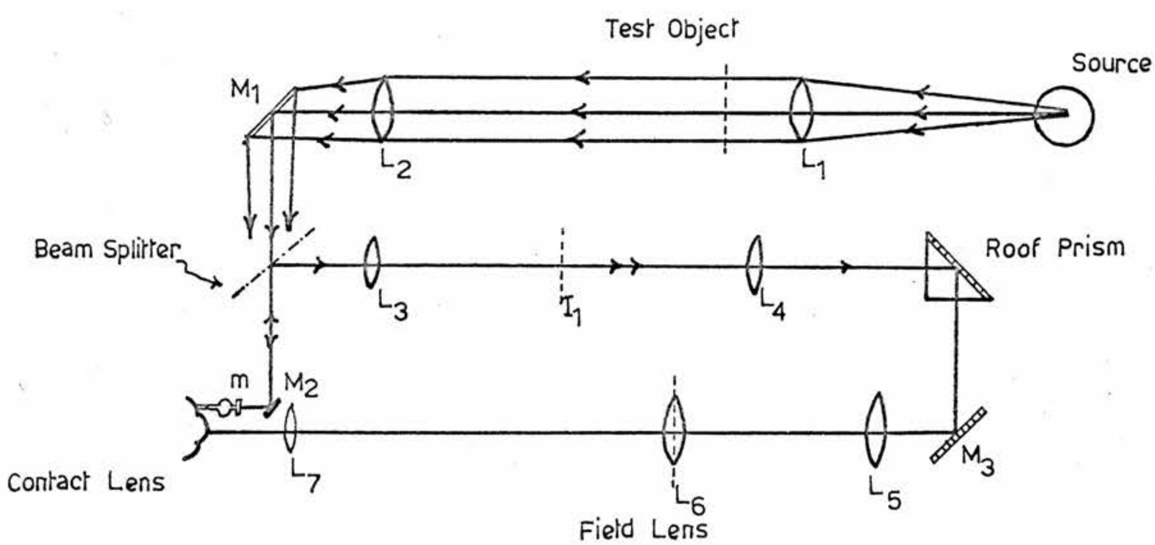
Diagram 2.iii. Original optical system for producing a stabilized retinal image as used by Ditchburn and Ginsborg (1952); from Ditchburn and Fender (1955), page 128.

2.2. Optical Lever Systems

The first optical lever systems developed independently by Ditchburn and Ginsborg (1952) and Riggs, Ratliff, Cornsweet and Cornsweet (1953) were relatively simple; however, subsequent improvements have introduced considerable complexity, but have led to increased versatility. In outline, the simplest system consists of an optical set-up which images the test object onto a screen via a mirror, which has been worked on the temporal side of the corneal bulge of a contact lens (C.L.), fitted to the observer's eye. The image on the screen is viewed by this eye through a system of mirrors, which are arranged to give a visual path twice as long as the distance from the C.L. mirror to the screen, thus compensating for the doubling of the angle of rotation of the beam projected from it (Diagram 2.iii.). The angular motion of the image, seen by the eye, is therefore the same as that of the eyeball, and the image of the test object on the retina remains stationary. These early systems only compensated for movements in the horizontal plane, as the normal to the C.L. mirror made an acute angle with the visual axis; thus only a component of any vertical rotation appeared in the upward movement of the reflected beam. This fact was not of serious consequence, as the targets used in these systems were vertical patterns. It was then shown by Fender (1955) that the eye rotates about the visual axis (torsional rotation); so if the normal to the C.L. mirror is not parallel to the



<u>Diagram 2.iv.</u>. Improved optical system for producing an accurately stabilized retinal image: Ditchburn and Fender (1955), page 129.



<u>Diagram 2.v.</u> Simplified normal incidence telescopic compensating system: Clowes and Ditchburn (1959), page 257.

visual axis, then the vertical and horizontal components of the projected image will contain components of this torsional motion, which, on occasions, are of sufficient magnitude to destabilize the image. These effects were overcome by Ditchburn and Fender (1955) by mounting the C.L. mirror on a stalk, so that the normal to it was parallel to the visual axis (Diagram 2.iv.). The moving of the C.L. mirror away from the surface of the contact lens, had the additional advantage that its surface was not dimmed by eye fluids. The remaining problem was the fact that when the translatory motion of the C.L. mirror had a component in the direction of the incident beam of light, it caused a corresponding shift in the projected image, but this was overcome by adjusting the projected beam of light so that it was incident on the mirror along the line passing through the centre of the mirror and the centre of rotation of the eye.

The more complex systems actually focused the image directly on the pupil (a Maxwellian view), and in 1959 Clowes and Ditchburn produced a much improved system, their measurements indicating that 99.7% of the natural eye rotations in the horizontal and vertical planes had been compensated for, and that the effect of translation was negligible: a simplified version of the system is shown in Diagram 2.v.; the actual system, however, had a more refined source and compensating pathway. This (normal incidence) telescopic compensating system has the C.L. mirror mounted normally to the visual axis as before, but use is made of a beam splitter, which enables the light incident on the C.L. mirror to be projected normally to it, thus giving simultaneous stabilization in respect of vertical and horizontal angular movements. In all of the above mentioned variations of the optical lever system, head movements are usually constrained by means of a dental biting board, and head rest, as any movement of the head imposes additional, translational movements on the eye.

The great advantage of the optical lever technique is that one is not restricted in one's choice of target, as virtually any form may be presented. There is also the benefit of being able to manipulate certain characteristics of the target, and to vary its degree of stabilization, this being easily achieved by varying the length of the compensating path of the light rays reflected from the C.L. mirror. Unfortunately, the optical lever system, due to having physical attachments to the eye (the contact lens and mirror structure), introduces a number of distinct disadvantages. Among the most important of these is the distinct possibility that the contact lens may slip relative to the surface of the eye, thus destabilizing the system. In addition to the slippage problem, there are a number of other drawbacks which are given a comprehensive coverage by Barlow (1963) and will be discussed in detail later. The size of field which can be utilized is limited in this method, as the torsional movements of the eye are not compensated for; so the larger the field, the more noticeable is their effect on outlying parts of the target.

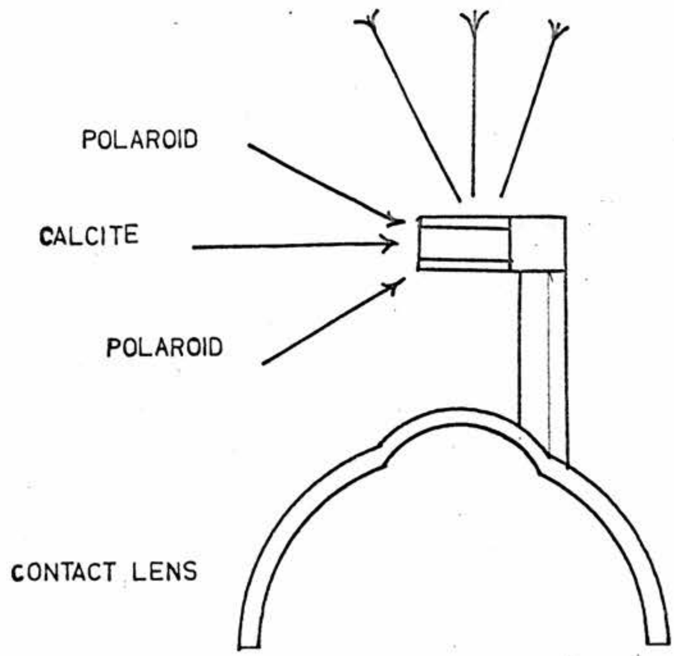


Diagram 2.vi. Contact lens assembly for producing stabilized interference fringes on the retina: Ditchburn and Pritchard (1956), from Clowes and Ditchburn (1959), page 253.

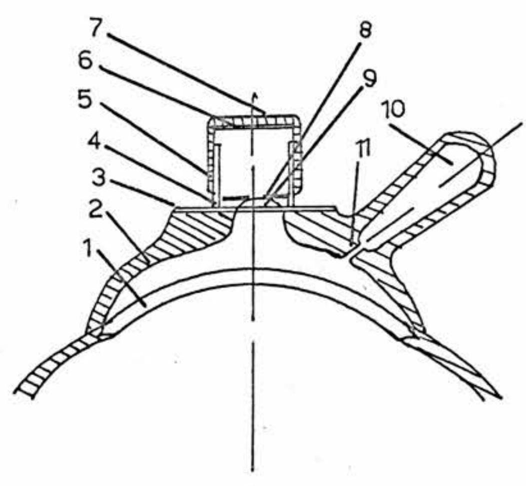


Diagram 2.vii. Modified rubber sucker stabilizing attachment: Yarbus (1956), page 436.

2.3. Ocular Target Attachments

This technique, which was independently developed by Ditchburn and Pritchard (1956) and Yarbus (1956), utilizes a contact lens or suction cap, to which the target mount is directly attached. Ditchburn and Pritchard's (1956) original device consisted of a calcite crystal sandwiched between two pieces of "Polaroid", this being attached, by means of a ball joint, to a stalk fixed to the side of a contact lens (Diagram 2.vi.). Illumination of the assembly results in the observer wearing it seeing a pattern of rings and brushes when the eye is focussed for infinity. Assuming that there is no slippage between the contact lens and the eye, then the image is stabilized, the centre of the pattern being in the direction of the optic axis of the calcite. Yarbus (1956) used a modified rubber sucker (2), linked to a rubber bulb (10), which was used to lower the pressure in the space between the cornea (1) and the sucker (Diagram 2.vii.). The centre of the sucker was cut out, and a fine glass plate (3) was attached to it; on top of the plate was mounted a short focal length lens (9) and a diaphragm (8), the target assembly (6 and 7) being mounted on an extendable metal cylinder (4 and 5) fixed to the perimeter of the glass plate. The diaphragm served to diminish distortions due to the spherical aberrations of the attached lens, and the fluctuations in accommodation of the lens of the eye. A local anaesthetic (dicaine) was used, and the subject's eyelids were taped back, the field

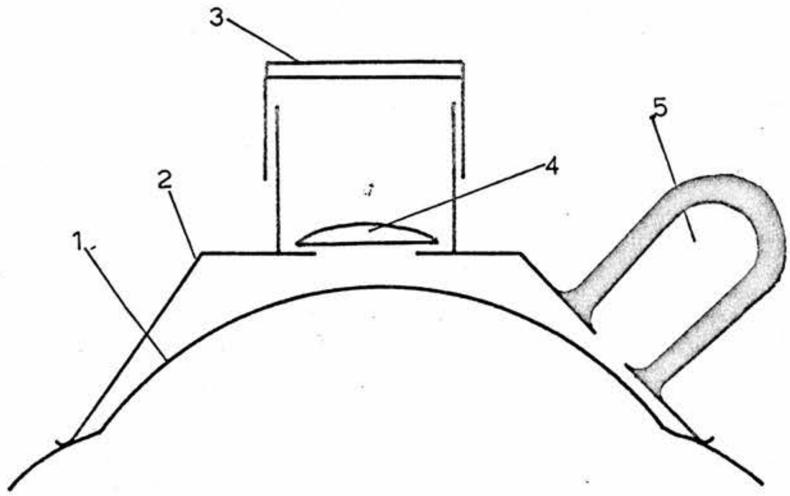


Diagram 2.viii. Improved cap stabilizing attachment: Yarbus (1957), page 684. This cap gives a stationary retinal image over the whole field of view: (1) cornea, (2) body of cap, (3) opal glass, (4) lens, (5) rubber bulb.

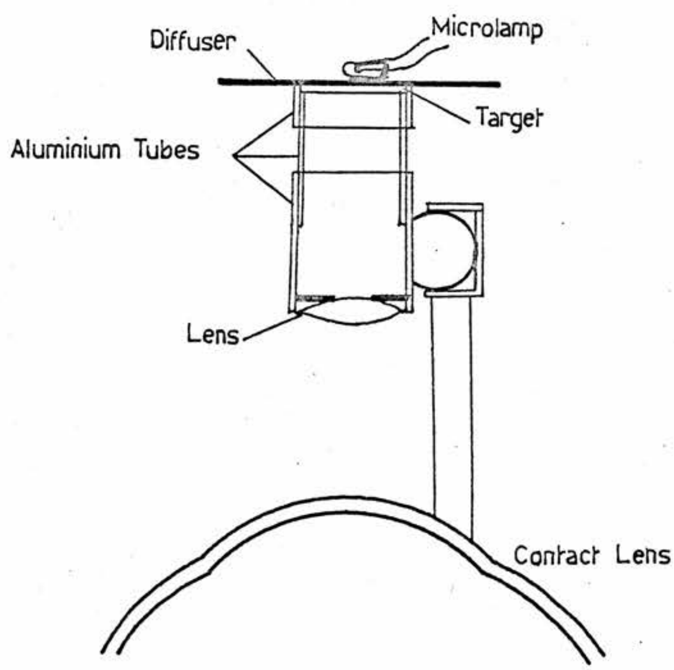


Diagram 2.ix. A collimator stabilizing system: Pritchard (1961a) from Pritchard, Heron and Hebb (1960), page 69.

of view through the system being up to 15°. An improved version of the above cap system was produced by Yarbus (1957b), the rubber sucker cap being replaced by a duralumin cone with crimped edges to prevent it from moving over the surface of the eye, and the lens was improved in quality (Diagram 2.viii.).

A much improved development of Ditchburn and Pritchard's (1956) system was presented by Pritchard (1961a). The polaroid calcite "sandwich" was replaced by a very small collimator, and the target, resting under a diffuser illuminated by a tiny surgical bulb, was viewed with an effective magnification of about thirty (Diagram 2.ix.). A distance of 0.4 m.m. at the target, therefore, represented 2°, and a distance of 3 μ represented one minute of arc in the visual field, thus the set up was not suitable for producing small images of very fine definition on the central fovea. As the image of the target is viewed at infinity, the fluctuations in accommodation (Campbell, Robson and Westheimer, 1959), which are present in Yarbus' (1956) viewing conditions, are not present because the suspensory ligaments are taught. Other advantages of the stalk collimator system are that neither a local anaesthetic nor retraction of the eyelids is required.

Further attempts to develop a 'universal' contact lens, which would have advantages over the previously mentioned systems developed by Yarbus (1956 and 1957a and b), have been made by Evans (1965a). After a relatively unrewarding excursion into rubber-based systems, Evans developed a universal contact lens system, whose origin lay in the gonioscope, which is a straightforward ocular attachment used in the clinical examination of the fundus. Like the gonioscope, this universal C.L. had a perspex bowl with a steep corneal clearance, but on the corneal haptic portion there was a perspex button (having no optical power) onto which was fitted an aluminium tube. Once this device had been placed on the eye, the lens/target holder system was attached to the tube. Good image quality and reasonable stabilization were obtained with this system, the optimum target size being approximately 5°.

The main advantages of the contact lens/suction cap (with target attachment) systems are: (a) torsional rotations of the eye, as well as vertical and horizontal, are compensated for; (b) once the target holder/lens assembly has been focussed, no subsequent adjustment is necessary; and (c) the targets can be easily interchanged during an experiment. In comparison with the optical lever systems, its main disadvantage is that the degree of stabilization cannot be varied. As with the optical lever system, there are also the disadvantages of image distortion, and the possibility that the contact lens assembly may slip relative to the surface of the eye, and thus destabilize the system: this possibility will now be considered in some detail.

2.3.1. Contact Lens Slippage

The possibility that a contact lens might slip relative to the surface of the eye was given consideration by the early researchers in this area. Ratliff and Riggs (1950), during their measurements of involuntary movements of the eye (using an optical lever system), investigated this problem. They found that the records obtained from a very small mirror, attached to a small disc of absorbent tissue paper and placed directly on the eye, were very similar to those obtained by means of their contact lenses. They therefore concluded that, "It seems very unlikely that these two very different attachments to the eye, would yield such similar results, unless each were following the movements of the eye with a fair degree of accuracy" (page 700).

Ditchburn and Ginsborg (1953) and Ginsborg (1953) showed that with voluntary eye movements up to 4° of arc in magnitude, even when the eye was moved very sharply, the contact lens followed the eye to within a few minutes of arc ($\pm$ 3'). Riggs, Armington and Ratliff (1954) varied the mass of their contact lens unit by as much as 20 to 1, but found that the resulting records showed similar amounts of eye tremor throughout. Their use of a minute chip mirror attached directly to the sclera also resulted in tremor motions very similar to those obtained with the aid of a C.L. However, the accuracy of the above methods is such that they cannot rule out the possibility of slippage of 3 minutes of arc between the contact lens and the eye, and this led to the development of more refined techniques.

Byford (1962) made a thorough investigation of the fidelity with which a contact lens might follow the horizontal movements of the eye under a number of conditions, using the following techniques to measure the displacements of the scleral or corneal surface: (a) a travelling microscope focussed on the eye or contact lens, (b) a photoelectric recording system, and (c) high speed cinephotography combined with simultaneous photoelectric recording. During fixation changes, he could not demonstrate any relative displacement between the eye and the lens for movements less than 30' of arc, a mean slip of less than 1' of arc being detectable by the statistical technique employed. However, he did find that for eye movements in excess of 1°, the conventional contact lenses used in his experiments did slip relative to the cornea, and with voluntary eye movements to an off-centre fixation point, he found that whatever position this point was approached from, either left or right, the lens lagged behind by approximately 6' of arc. Byford, himself, makes the point that the conclusions from his study of horizontal movements could probably be extended to vertical movements, but that it would be unwise to extend them to torsional rotations. Byford's techniques have the advantage that they are free from subjective measurements on the part of the subject, but nearly all the slippages investigated resulted from voluntary eye movements.

However, Barlow (1963) has made a comparison of the extent to which two different types of contact lens are subject to slippage: namely, the full scleral fitting contact lens and the lightweight suck on limbal seating cups, similar to those used by Yarbus (1957b). By comparing the relative positions of a 'stabilized after-image pointer', and an opposing pointer mounted on the contact lens target holder, Barlow was able to show qualitatively that there was slippage. To quantify these findings, the contact lens target was changed to a straight edge with two identical squares of polaroid, mounted side by side, with their planes of polarization differing by 90°. A brief flash of polarized light was then delivered, this being in the same plane as one of the squares, and after 5 - 10 seconds another flash was given, but its plane of polarization was 90° to that of the first. The contact lens was then removed, and if the contact lens had slipped during the interval between the flashes, then a step would be noticeable in the after-image of the two squares, this being inspected by looking at a white screen. The extent of the slippage was measured by matching, as closely as possible, a variable step, seen at the same distance away as the screen, with that of the after-image. Barlow's findings were that the full scleral C.L. slips by as much as $\pm$ 3.5 minutes of arc in a five to ten second interval, while even with the Yarbus type of limbal seating suck-on contact lens, it was difficult to achieve stabilization better than $\pm$ 40 seconds of arc. An indication as to the accuracy of the method may be gained from the fact that a control experiment, with a step after-image (estimated to subtend 12 minutes of arc), gave a mean result of 10.5 $\pm$ 0.31 minutes of arc for ten attempts to match it with the variable step.

Bennet-Clark and Ditchburn (1963) measured the amount of contact lens slippage for various degrees of reduced pressure between the contact lens and the eye. They measured the relative movement between the after-image of narrow straight lines, and the target which consisted of a series of transparent bars. The intensity of the flash was such that it evoked considerable blinking, and with no pressure reduction, relative movements of between 3 and 8 minutes of arc occurred as often as ten times in a twenty second interval, the blinks causing movements of between 15 to 30 minutes of arc. With a pressure reduction of 5 cm. mercury, relative movement was detectable for 10 seconds after the flash, but subsequent movements were too small to be reliably detected, the relative movement only being estimable to about one minute of arc. The blinks caused movement of about 4 minutes of arc. In agreement with Byford (1962), they found a lag of up to 30' arc when their subjects made voluntary movements of their eyes through $\pm 15^{\circ}$, this being reduced by a factor of nearly ten, when the pressure was reduced by 5 cm. of Hg. They also investigated the accuracy of their tests of slippage, and found that control steps of 2.5' and 5' of arc, had an error of estimation of up to 14%.

It must be pointed out that the after-image method of measuring the degree of contact lens slippage has the disadvantage that it relies on subjective matching on the part of the observer, and causes considerable blinking, which results in substantial slippage for the first few seconds, thus giving rise to a marked overestimation of the degree of slippage, which would occur under normal fixation conditions. Nevertheless, from the above investigations, it would appear that one cannot discard the very distinct possibility that all stabilization techniques, which utilize contact lens attachments to the eye, are, to a varying degree, subject to slippage between the contact lens and the surface of the eye.

2.4. Flash After-imagery

The after-image, resulting from stimulation by a bright source of light, is in all probability stationary on the retina, as Craik (1940) and Brindley (1959) have shown that such an after-image is primarily determined by photochemical events in the receptors, this being especially true of the after-image after its first fifteen seconds (Brindley, 1959). However, due to physiological nystagmus, the viewing of the source for even one second will result in its image being 'played' over the surface of the retina, and the resulting after-image will have a differential composition, the contours being somewhat diffuse, relative to the central area. A very short flash of light should, therefore, produce an after-image whose contours will be sharply defined.

The optimum duration of such a flash can be derived from Riggs, Armington and Ratliff's (1954) investigation, which found that during a 0.01 second exposure the retinal image moved through 5 seconds of arc in only 38 per cent of the cases, while motions of over 10 seconds of arc were found in only 10 per cent of the cases, the median extent of motion during a 0.1 second flash being 25 seconds of arc (roughly the diameter of a single retinal cone). They concluded that, "0.1 second is often a practical exposure time for the control of eye movements, and 0.01 second is an exposure time which nearly always results in a 'stopped' retinal image" (page 321). It should be noted that if the flash source used to produce a 'stopped' after-image subtends an angle greater than the rod-free area of the fovea, which is between $1^{\circ}40'$ and 2° of arc (Polyak, 1957), then the later stages of the after-image may appear as an annulus, the central 2° area being invisible (Alpern and Barr, 1962). This is due to the regeneration time for the cone pigments being far shorter than that for the rods (i.e. Hecht, Haig and Wald (1936); Hecht, Haig and Chase (1937)). Thus to avoid the effects of differential regeneration, the targets used in 'stopped' flash after-image experimentation are normally confined to the homogeneous, rod-free area of the fovea.

Hochberg and Hay (1956) were among the first investigators to use flash after-images to eliminate the effects of physiological nystagmus, their interest being the study of figural after-effects under these conditions. Barlow's (1963) use of an after-image technique to measure contact lens slippage has been mentioned in the previous section, and initiated interest in the use of flash after-imagery as a means of stabilizing an image on the retina. The first to study patterned 'stopped' after-images were Bennet-Clark and Evans (1963), using the following technique: the targets were cut out of black paper and backed by tracing paper; these were illuminated from behind by a photographic flash unit, using flash bulbs giving a flash duration of about 20 milliseconds, and, when viewed at 3 metres, the targets subtended an angle of approximately two degrees. The subject was, in each instance, asked to fixate (monocularly) a certain point on the target, the experimentor then initiated the flash, and extinguished the room lights, leaving the subject in complete darkness to observe the resulting after-image, which remained visible for at least ten minutes. Reports on the after-image were taken after five minutes, and subsequent exposures were made with alternate eyes, the inter-trial period being of at least 15 minutes duration.

The advantages of the technique of flash after-imagery are that it is simple and does not entail the relatively expensive use of a contact lens assembly for each subject, thus allowing many subjects to be utilized. It avoids the possible distortions of the image involved when the stabilization technique entails physical attachments to the eye, and the images thus produced are highly stable. However, due to the heterogeneous nature of the retina, apart from the rod-free area of the fovea, the target size is usually limited to just under two degrees. There is the disadvantage that relatively fine target structure is not particularly satisfactory, lines having to be fairly thick before they can be easily discernable in an after-image, and there is also no way of varying the degree of stabilization. Also, when using the flash after-image technique, there is the problem as to what extent continued external visual stimulation, at a relatively low level, is comparable with a waning photochemical reaction, initiated by an intense flash of light, but this point will be considered in the discussion.

2.5. Resume

There are four main techniques used to stabilize an image on the retina: (1) imaging of internal ocular structures such as the iris, capillary blood vessels or the macula lutea - such images are usually very stable and free from distortion, but the possible stimuli are limited solely to these structures, the degree of stabilization usually being invariant; (2) optical lever systems, which utilise a beam of light (reflected from a plane mirror attached to a contact lens) to project an image of the test figure through a compensated optical system onto the retina - although having the advantages of variable target configurations and degree of stabilization, this technique suffers from contact lens slippage and field size limitations; (3) ocular target attachment systems, which utilise a contact lens or suction cap to which the target mount structure is directly attached - assuming no contact lens slippage, then the resulting image is stabilized for all possible movements of the eye, but the degree of stabilization is relatively invariant (investigation into C.L. slippage seems to indicate that it is significant, it being a function of the type of C.L. deployed and the degree of suction existing between the lens and the cornea); (4) flash after-imagery, which utilizes the after-image resulting from a short, intense flash of light, passed through the target apertures - such images are very stable and free from distortion, but stimulus lines normally have to be relatively heavy and fall within a 2° field of view, the degree of stabilization being invariant.

3. CONSEQUENCES OF STABILIZATION

3.1. The Perceptual Effects of Stabilization

3.1.1. Effects of stabilization on visual acuity

3.1.2. Effects of flickering a stabilized image

3.1.3. Effects of induced movement on a stabilized image

3.1.4. Perceptual effects as a function of the degree and type of stabilization

3.1.5. Colour; movement within a stabilized field; and brightness

3.2. The Organization of the Breakdown of Perception

3.3. Resume

3. CONSEQUENCES OF STABILIZATION

In this chapter, consideration will first be given to the perceptual effects of stabilizing a retinal image, followed by an examination of the organization of the breakdown of perception under these conditions, and ending with a review of the implications of these phenomena to perceptual theory.

3.1. The Perceptual Effects of Stabilization

In the introduction, it was mentioned that, even under conditions of steady fixation, small involuntary movements of the eye are present. Ginsborg (Ditchburn and Ginsborg, 1952), using the optical lever technique, carried out a set of experiments in which the horizontal components of these movements were stabilized. Mention is made of the fact that Ditchburn made some preliminary experiments in Dublin in 1945, but was unable to obtain consistency in his findings, or make the necessary checks with the, then, available equipment. In the 1952 investigation, the target viewed was a vertically divided, circular patch of light, subtending one degree in the visual field, the brightness of the right hand area being capable of being made 30, 40 or 60 per cent of that of the left hand area. Under the stabilizing conditions, the line of demarcation disappeared, the patch becoming homogeneous for two or three seconds at intervals of about one minute. It was also found that the contrast threshold, under these conditions, was very much higher than the normal threshold for the same brightness. According to Ditchburn and Ginsborg, it is possible that the eye recognises the abnormality of the situation and makes some adjustment such as accommodation, which destabilizes the image and causes its reappearance.

Independently of Ditchburn and Ginsborg (1952), Riggs, Ratliff, Cornsweet and Cornsweet (1953), using a somewhat similar optical lever system, made a comparison of the perceptual effects of viewing vertical lines, varying in width from 5.8 to 93.3 seconds of visual angle, under three conditions of eye-movement: normal, compensated (horizontal plane only) and exaggerated by a factor of two. The vertical test line was viewed in a circular test field, which was in the centre of a stationary annulus, having an outer diameter of 67', thus providing a stationary fixation field. Two subjects were utilized, each monocularly viewing the target field for periods of one minute, and recording the presence or absence of the line by means of a key. Their results showed that, under the compensated condition, the line soon began to fade out and finally disappeared completely leaving only the projected bright circular field, which occasionally disappeared itself. The wider the test line, the longer it took to disappear and it would also reappear intermittently. Under normal viewing conditions, fine lines did fade, but reappeared intermittently while heavier lines seldom disappeared; however, under the exaggerated condition even the finest lines seldom disappeared. In order to obtain quantitative evidence, they calculated the width of the line which could just be seen for 50 per cent of the time during the one minute exposure, and obtained 31, 19 and 6 seconds of visual angle for one subject and 24, 14 and 8 for the other, for the 'compensated', 'normal' and 'exaggerated' conditions respectively.

3.1.1. Effects of stabilization on visual acuity

The second part of the investigation by Riggs *et al.* (1953) was concerned with visual acuity under the same three conditions as before, but the test object was presented only briefly, and the subject simply indicated whether or not he had seen the fine line during the exposure, which was of one of the following durations: 0.034, 0.110, 0.213 and 0.472 second. For short flashes, there were no marked differences among the three experimental conditions. However, the 'compensated' image was slightly better than the other two conditions for short flashes, while for flashes in excess of 0.2 second the 'exaggerated' condition was more favourable, the 'normal' condition yielding results which lay between the other two conditions. Riggs *et al.* came to the tentative conclusion that although eye-movements do not enhance visual acuity, they do seem to have a primary function in overcoming the loss of vision due to unchanging retinal stimulation.

An earlier paper by Ratliff (1952) also concluded that eye-movements were detrimental to monocular acuity. Using randomly presented test fields containing either a horizontal or a vertical line grid, and recording only the horizontal components of eye-movements, Ratliff was able to show that for 75 m.sec. exposures of these test fields, subjects were less able to report their orientation during exposures, when there was drifting or large amounts of rapid tremor, than when these were minimal. The above two findings of visual acuity under conditions of normal and stabilized vision, were further qualified by Keesey (1960), using a modified 'stalk' optical lever system. Using seven exposure times, varying from 0.020 to 1.280 seconds, visual acuity was determined for three types of test targets: a vernier, consisting of two vertical lines, one lying offset either to the right or to left of the other; a fine opaque vertical line; and a grating, whose lines were either orientated horizontally or vertically. It was found that acuity reached the same optimum exposure value for both normal and stabilized viewing conditions, increasing progressively from 0.02 to about 0.2, after which there was no improvement. It would thus appear that an important parameter in determining the effectiveness of the acuity test object is exposure duration, and on the basis of these findings Keesey (1960) comes to the conclusion, "that acuity is mainly based on the discrimination of the spatial pattern of retinal illumination, regardless of any temporal changes of intensity pattern of the receptor cells" (page 774).

Finally, perhaps, mention should be made of Millodot (1966) who investigated foveal and extra foveal acuity under stabilized conditions (optical lever) using Landolt rings, and found that, after allowing for a reduction in retinal illumination, there was a small loss in foveal acuity when compared with acuity under normal conditions. However, as only one subject took part in this particular experiment, no definite conclusion can be drawn.

3.1.2. Effects of flickering a stabilized image

Ditchburn and Fender (1955) and Cornsweet (1956) have investigated the visibility of a stabilized retinal image under conditions of flicker. Ditchburn and Fender (1955) produced a flickering stabilized image by interrupting the source of light (equal periods of dark and light) at various frequencies. Using an improved optical lever system, which compensated for both vertical and horizontal components of eye movement, and a black line of 5' arc wide on a circular 1° field (having a brightness of 25 m.L., i.e. 79.6 cd/m^2), they found that in varying the flicker rate from 0 to 60 c.p.s., visibility increased up to about 20 c.p.s., where the target remained visible for 97% of the time, 20 c.p.s. being the critical flicker frequency under these conditions. Further increases in flicker rate resulted in a steady decrease in visibility, until, at 60 c.p.s., it was little better than that under the steady stabilized condition.

It is, perhaps, worth pointing out that Ditchburn and Fender (1955) found that subjects greatly overestimated the brightness of the visual field at high rates of flicker, the mean illumination remaining constant at about 10 m.L. - one subject overestimated by as much as a factor of 10^2.

Cornsweet (1956), however, produced flicker by alternating the presence or absence of a vertical black line (having a width of 5' of arc) against a bright circular background (253.9 m.L., i.e. 808.2 cd/m^2) with an outer annulus, the set-up being very similar to that of Riggs, Ratliff, Cornsweet and Cornsweet (1953). The flicker rate was varied from 0.8 to 4.4 c.p.s. for one subject, and 3.2 - 9.6 c.p.s. for the other. It was found that at the slower rates the stabilized image remained visible for periods of time similar to those under normal viewing conditions, but as the flicker rate was increased, the disappearance time increased until, at upper range values, the time visible was very similar to that under the standard stabilized condition.

The fact that the two sets of results are so dissimilar, Ditchburn and Fender finding a steady increase in visibility up to 20 c.p.s., while Cornsweet found a sudden increase in visibility at low flicker rates, with a steady decrease up to 4.4 c.p.s, or 9.6 according to the subject, might be explained partially on the grounds that the methods of producing flicker were different, as Ditchburn and Fender flickered the entire field, while Cornsweet flickered only the stimulus line within the visual field. However, Yarbus (1956) found that when the stabilized field was illuminated by intermittent light, the perception of objects did not disappear when the frequency was less than flicker fusion, but disappeared when it was equal to or greater than that frequency, thus casting some doubt on Ditchburn and Fender's (1955) findings.

Fiorentini and Ercoles (1960) in an attempt to resolve these differences made an intensive investigation into flicker phenomena, using both intermittent illumination of the whole figure and intermittent presentation of the line against a steadily illuminated background. Using vertical lines of 30", 2' and 12' of arc in width, with a field luminance of 1.4 or 1.9 nits (cd/m^2), they found that for the differing widths and both conditions of flicker, the disappearance time was at a minimum for 1 c.p.s., increasing rapidly with increases in frequency up to 4 or 5 c.p.s. There was then a gradual increase in disappearance time with further increases in frequency, until it reached a level similar to that observed under equivalent conditions of constant illumination. The disappearance time rate was slightly higher for intermittent illumination than for intermittent line presentation, and the results were in close agreement with those of Cornsweet (1956). The above results clearly show the need for intermittent stimulation of the rods and cones for the maintenance of visual perception.

3.1.3. Effects of induced movement on a stabilized image

From the point of view of ascertaining the amplitude and frequency of eye-movements which are most beneficial to maintained vision, Krauskopf (1957) performed experiments in which retinal image motion was a controlled variable. Using an optical lever system, and lines of varying width (10", 1', 4' and 8' of arc), Krauskopf induced various degrees of movement by the controlled rotation of one of the mirrors in the optical system about its vertical axis (these movements having frequencies of 1, 2, 5, 10, 20 or 50 c.p.s., with peak-to-peak amplitudes of 30", 1', 2' or 4'), and measured the 50% threshold for each combination of width, frequency and amplitude. Krauskopf concludes that oscillations below 10 c.p.s. enhance contrast thresholds if they are of a magnitude of about one minute of arc or greater. However, high frequency motions have detrimental effects, or, if their amplitude is less than one minute of arc, then they have no measurable effect. Using stabilized Mach bands, Keesey and Riggs (1962) reaffirmed the value of low frequency, high amplitude motions of the retinal image for the maintenance of vision. Considerable care must, however, be exercised in generalizing from Krauskopf's experiments using externally controlled sinusoidal motion to the eye motions usually present under normal fixation, but it would appear that the relatively slow, large amplitude motions are the most advantageous for maintaining vision, when compared with stabilized vision.

Subsequent investigation of controlled movements of the retinal image, by Ditchburn, Fender and Mayne (1959), necessitate certain qualifications to the above conclusions. Using the much improved optical level system of Ditchburn and Fender (1955) (modified so as to be able to impose onto a stabilized image, motion similar to the drift, flick and tremor of normal eye-movements), and a target consisting of a fine vertical black line (2.75 - 5' of arc in width) on a bright circular

1° field (having a brightness of 15 - 50 m.L., i.e. 47.8 - 159.2 cd/m^2), it was found that imposed motion similar to the drift component of normal eye-movements had little effect in preventing fade-out, while imposed motion similar to a natural flick produced a very sharp regeneration of the image, which quickly faded out again. When small amplitude tremor motions, having frequencies of 4, 8, 12 or 20 c.p.s.,* were imposed, it was found that for amplitudes less than 20' of arc, the level of visibility was below that obtained for a stationary line in stabilized vision, while for amplitudes of about 20' of arc there was a steep rise in visibility, the target line being visible nearly all the time for amplitudes greater than this value. From these results, Ditchburn <u>et al</u>. conclude that there is maintenance of visual 'acuity' by tremor of the eye, "only if there is a summation of effects over the whole frequency spectrum of eye-movements" (page 106). They also point out that no single component of normal eye-movements is alone capable of maintaining vision, and that the ability of normal eye-movements to amintain vision, "must depend upon additive interplay between the different components" (page 107).

It is interesting to note that Gerrits <u>et al</u>. (1966), using a much modified Yarbus suction cap system, found that when a dark annulus (stabilized when stationary) was oscillated (a form of eccentric rotation) against a stabilized green

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* A 15 c.p.s. induced tremor gave somewhat atypical results.

background, that frequencies less than one per second resulted in the observation of "on" and "off" borders. The centre of the annulus was visible as a green circular patch when the frequency was one per second, while higher frequencies of about 10 sec^{-1} were ineffective in "filling in the hole", the whole field disappearing from view. This finding thus provides further evidence as to the importance of low frequency movements in sustaining vision.

3.1.4. Perceptual effects as a function of the degree and type of stabilization

The length of the duration of disappearance of a given width of line has been used in some investigations (i.e. Ditchburn, 1955) to indicate the extent to which stabilization has been achieved. Riggs and Tulaney (1959), using an optical lever system and a bipartite field surrounded by an annulus, varied the length of the viewing path, theoretically perfect compensation for eye-movement occurring only when this path was twice that of the projection path. Deviations from this ratio introduced movement of the image across the retina, its extent being a function of the discrepancy. As expected, they found that the disappearance of the separation line between the two halves of the target was greatest for the 2:1 ratio, corresponding to theoretically perfect stabilization, but with a 10% error in stabilization the decrease in disappearance time was only beginning to be significant. However, when the error was 20%, the decrease in disappearance time was definitely significant. They also varied the luminance ratios between the two halves of the test field, and found that as this ratio increased, the disappearance time decreased. It would appear from the above findings that small errors in the setting up of an optical lever stabilizing system have very little effect on the disappearance time of simple test targets, especially where the levels of contrast are low.

Consideration must now be given to the possibility of perceptual artifacts inherent in certain types of techniques deployed to stabilize an image on the retina. The distinct likelihood of a contact lens slipping relative to the eye, has been given consideration in section 2.3.1., thus giving rise to the probability of regeneration of a stabilized retinal image due to shifting the contours of the stimulus object to a 'fresh' set of receptors. Slippage, which was transverse to a straight line, would (if of sufficient magnitude) give rise to complete regeneration while slippage parallel to the line would have little effect unless of considerable magnitude, the line's locus being only slightly changed. According to investigators, whose stabilizing technique imaged internal ocular structures onto the retina, the images so stabilized disappeared in a few seconds and did not reappear again unless mechanically destabilized, e.g. Ratliff (1958), Campbell and Robson (1961) and Cornsweet (1962). As well as avoiding the problem of contact lens slippage, this technique also forestalls artifacts due to changes in accommodation, pupil area variations, vignetting in the optical pathway and changes in interocular tension (Campbell and Robson, 1961). Similar effects to those mentioned above have been obtained, using suction cap attachments: Yarbus (1956) and Gerrits, de Haan and Vendrik (1966) found that once the perception of a stabilized image had disappeared it did not reappear unless there was some form of mechanical destabilization or change in stimulus input, the time taken for disappearance to occur being of the order of a few seconds. Millodot (1965), using his own type of C.L., also obtained similar results.

However, Barlow (1963), who was uneasy about the image quality of Yarbus' suction caps, produced an improved Yarbus type of contact lens, and reported that images stabilized by it were seen with full clarity only for the first few seconds. This was followed by the loss of some of the fine detail and contrast of the original image, after which there was a period of about a minute during which the remaining textureless, shadowy image disappeared and regenerated, becoming rather less distinct with each repetition, until there remained only a very blurred, and very low contrast version of the original image, which persisted without fluctuation, unless destabilized.

Other investigators, such as Fiorentini and Ercoles (1963), do not accept the fact that experiments stabilizing internal ocular (fundus) structures preclude the existence of spontaneous fluctuations of contrast sensitivity. They point out that the contrast in the image of the eye fundus is relatively low, and that it is well known that the maintenance of visibility of stabilized objects is a function of the extent of figure-ground contrast (cf. Riggs and Tulunay, 1959). Using a 1^{o} bright circular field having a luminance of 0.3 m.L. (0.95 cd/m^2) and a vertical bar test object subtending 27 x 3 minutes of arc and recording horizontal eye-movements, Fiorentini and Ercoles (1963) found that there were occasions when there was spontaneous regeneration of the test line, i.e. it was not preceded by or accompanied with a flick capable of regenerating the image, by causing the lens to slip relative to the cornea.

From the above set of findings, it would appear that on occasions even perfectly stabilized images do regenerate spontaneously, though perhaps not always with the same degree of definition as the original image. What, then, are the other possible means by which a stabilized image may be made to reappear? It has been shown that stimulation of other sensory modalities, especially auditory, is capable of regenerating a stabilized image which has disappeared (Pritchard and Vowles, 1960,* as cited in Pritchard, Heron and Hebb, 1960). Pritchard (1958) has also shown that it is possible to transfer one's attention within a stabilized field subtending only a few degrees, and thus alter the amount perceived, the area under attention usually remaining visible for longer than the rest of the field.

The visibility of a stabilized image is also, in part, a

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* This particular paper was withdrawn from publication.

function of a type of contra-lateral stimulation. Using a modified version of the Riggs _et al_. (1953) apparatus, so designed to stabilize images on both retinas, Krauskopf and Riggs (1959) investigated interocular transfer in the disappearance of stabilized images. A small dark bar was presented stabilized to one eye for 30 seconds as a conditioning stimulus, followed by a 30 second test exposure to the other eye. The bar was offset from an unstabilized fixation spot, and lay within a 1^{o} test field surrounded by an unstabilized fixation annulus. As a conditioning or test stimulus, the bar fell on non-corresponding parts of the two retinas on the control trials, but on corresponding parts of the retinas in the experimental trials. It was found that there was a significant enhancement in the disappearance of the test bar in the experimental situation, i.e. when the corresponding region of the other eye was stimulated. Krauskopf and Riggs concluded that, in addition to photochemical adaptation processes, there must have been some degree of neural adaptation at, or beyond, the level at which impulses from the two eyes intersect, or some form of neural mechanism which could exert centrifugal control over a peripheral sensory process. The effects of simultaneous contralateral visual stimulation on the visibility of stabilized images has been investigated by Cohen (1961). The subjects viewed a stabilized image of a 2' x 2^{o} black line on a white background (using a collimator C.L.), while three types of visual stimulation were presented to the other eye:

1) darkness, 2) diffuse light and 3) patterned light. It was found that patterned light was the most effective in maintaining the visibility of the stabilized image, while darkness was the least effective. Cohen concluded from these findings that the fading of stabilized images is influenced by central factors, stabilized visibility being a function of the complexity of contra-lateral stimulation.

At this point it is worth listing other artifacts mentioned by Barlow (1963), all of which can cause misleading results when working in this area with contact lenses. Possible sources of image movement, other than actual slippage of the contact lens relative to the cornea are: slight movements of the eye lens, especially when the eye is accommodated for near vision, as the suspensory ligaments are slack; fluctuations in accommodation when the eye is accommodated for near vision probably giving rise to slight changes in image sharpness, but these fluctuations disappear when a target is viewed at infinity or when a cycloplegic is instilled (Campbell et al., 1959); in conjuction with the artificial pupil, pupil changes may cause a variable amount of vignetting. According to Barlow, these three artifacts can be eliminated by using homatrophine. Retinal ischaemia (a local anaemia caused by local obstacles to the arterial blood flow) can be caused by distortion of the eye-ball and the raising of the intra-ocular pressure due to the use of high suction contact lenses, thus giving rise to the fading of vision.

Poor optical conditions such as the inner lens surface steaming up, corneal curvature changes (which alter the focus) and corneal misting can all distort image quality in the suck-on type of contact lens, and the outer surface of certain contact lenses is particularly prone to smearing or wetting. The chromatic aberration, already present in the eye, can be further increased by using lenses of short focal length (the shorter the focal length of a lens, the more difficult it is to correct for chromatic aberration, and the resulting distortion may well become the limiting factor. If, in attempting to overcome chromatic and other aberrations, the entrance pupil is made too narrow, then image resolution will be marred by diffraction. Another disadvantage of having a small diameter pupil is that it also renders the eye more sensitive to trans-scleral light, thus decreasing image contrast and possibly mimicking fading; a decrease in trans-scleral light could induce regeneration of a stabilized image. Barlow (1963) also makes the point that the image quality of the contact lens should be carefully checked to ensure that it is nearly normal when the image is unstabilized.

3.1.5. Colour; movement within a stabilized field; and brightness

Colour: According to Yarbus (1957a), when a stabilized object is viewed against an unstabilized coloured background, it is visible for 3 - 4 seconds and then blends into the colour of the background. Subsequent experimentation by Yarbus (1957b), using duralumin (instead of plastic) bodied suction caps with either a pinhole or a glass lens, showed that colour disappeared from a stabilized field in 1 - 3 seconds, leaving an empty field, this usually being some shade of homogeneous grey. This finding is analogous to that of Cohen (1958), who, using a homogeneous chromatic Ganzfeld, found that after three minutes of adaptation an achromatic field was described in 80% of the reports, the remaining 20% indicating only a trace of colour. Yarbus also found that if the other eye was illuminated by coloured light, then the empty field would appear to be tinged with the same colour. Further investigation of a stabilized field against an unstabilized background showed that the empty field would not fuse with the background if it consisted of coloured areas, smaller than that of the stabilized field, but would remain dark grey. However, Pritchard (1961b), using his contact lens/collimator system, has shown that if the field consists of the three primary colours, red, green and blue, then there is very soon only a colourless field of three different brightnesses, which disappear with time, leaving a homogeneous grey.

Clowes (1962), using an optical lever stabilizing system and a 1° circular bipartite field, in which each segment was illuminated by a different primary colour, found that discrimination was impaired to different extents for the three primary colours. Among the effects reported by the subjects were: a fusion of colour between the blue and the green segments; an apparent desaturation of stimulus colour, which was most marked for green, and partial or total fade-out of the stimulus field, this being most marked for blue-green. Krauskopf (1963), using an optical lever system, examined the effects of stabilization on targets consisting of a central disc of one colour subtending 1^{o} 4', and an annulus of another colour subtending 2^{o} 14'. The diameter of the stabilized field was 1^{o} 56', thus leaving a narrow unstabilized surround. The luminance of the central disc was varied between trials to produce contrasts above and below equality for all colour combinations, the luminance of the annulus remaining constant. Over wide ranges of luminance, it was found that the central disc intermittently disappeared leaving a homogeneous field identical in colour to that of the annulus, the effect being most pronounced when the outer and inner field luminances were equated. Krauskopf (1963) concludes that, as sensory information concerning the contour between the disc and the annulus is absent under conditions of stabilization, the whole field takes up the colour of the annulus, since the only information concerning a contour is between the unstabilized surround and the annulus.

Beeler, Fender, Nobel and Evans (1964), using both optical lever and contact lens/collimator stabilizing systems, and colour transparencies of Ishihara plates (normally used for testing for colour blindness), found that flickering illumination of frequencies between 4 - 8 c.p.s. (which normally maintains the visibility of a stabilized retinal image), did not prevent colour desaturation effects (except for red lines on a grey background). Under normal stabilization, the plates, which are made up of numerous small coloured circles with a figure of different hue to that of the background, often appeared as a set of "uniformly bright monochromatic circles". The findings are interpreted as indicating that hue discrimination and form perception are mediated by separate mechanisms, as the two types of perception have been shown to fail independently.

Movement within a stabilized field: Yarbus (1957b) also investigated the effects of moving small circular 3° test objects against a large stabilized coloured background. It was found that a moving black test object appeared to have a colour identical to the after-image colour (in darkness) of the stabilized background, which remained an 'empty field'. A moving white test object initially appeared white, but after 30 - 40 seconds took on a hue complementary to that of the stabilized background, which still remained an 'empty field'. These and other observations by Yarbus (1957b) led him to the conclusion that the apparent colour of a moving object on an empty field background could be markedly varied according to the experimental conditions and the state of the visual analyser, there being a tendency for the conservation of the differences between the object and the empty field.

Yarbus (1959) investigated the movement of an airbubble in a stabilized capillary tube filled with a black liquid, and found 'on and off-comets' corresponding with the two moving edges. However, Gerrits, de Haan and Vendrik (1966) have performed slightly more sophisticated experiments on movement across a stabilized field. A perspex rod having three parts (opaque - translucent - opaque) was moved backward and forward across a stabilized green field, the whole of which had disappeared and become dark before the movement was initiated. The leading edge of the translucent segment was seen as bright green with a less bright halo trail ("on"-trail) while the rear edge was seen as being intensely black, often purplish, with a dark halo trail ("off"-trail). The brightness and colour of the trails were found to be a function of stimulus intensity, amplitude, velocity of the movement, image locus on the retina and duration of stabilization before movement initiation. The "on" and "off" trails were taken as being visual evidence of the type of activity due to the stimulation of "on" and "off" retinal receptors. According to Gerrits _et al._, "the retinal 'on'-bursts presumably rapidly build up an activity in the higher centre, which both spreads slowly to the surroundings and slowly diminishes by local adaptation (provided that other effects are excluded)", while "the activity of the retinal 'off'-elements rapidly builds up a new activity in the higher centre which causes the perception of intense homogeneous darkness, if the 'brightness-activity' in the higher centre has disappeared by adaptation" (page 436).

Brightness: One investigation into brightness discrimination under conditions of stabilization has already been mentioned (Ditchburn and Ginsborg, 1952), in which stabilization was found to raise contrast thresholds well above those encountered under normal conditions for the same brightness. Confirmatory studies have been performed by Clowes (1961), who, using the improved optical lever system of Clowes and Ditchburn (1959) and a bipartite field, observed the subject's ability to make brightness discriminations under three conditions of retinal image movement: stabilized, normal and exaggerated. It was found that the ability to make brightness discriminations increased as the amount of retinal image movement increased.

Yarbus (1960a) investigated quantitatively the minimal changes in the field luminance at which differences in a stabilized test field are noticeable. Using a modified duralumin suction cap, he presented his subject with a uniform circular 11° test field, bisected by a thread subtending 3 minutes of arc. It was found that the rates of change in brightness required for the reappearance of the test field (threshold rates) were approximately equal in their absolute value for an increase or a decrease in brightness. For intensities ranging from a few apostilbs to a thousand apostilbs (1 apostilb = 0.3183 cd/m^2), the threshold rate of change in brightness rose proportionately with increases in field intensity, thus agreeing with the Weber-Fechner law, the ratio of the threshold rate to the value of the brightness of the field being approximately constant at 0.3, indicating that stabilized changes in brightness have to reach 30 per cent per second before they become apparent. Yarbus (1960b), using a 20° field, has also shown that after 2 - 3 seconds the empty field occurs, even when the stimulus field was the filament of a very high intensity incandescent lamp. Step-wise increases or decreases in filament intensity caused reappearance, and the switching off of the lamp caused "the appearance of the dazzlingly bright filament which then completely faded out" (page 339), thus indicating the activity of the 'off' receptors in the retina.

3.2. The Organization of the Breakdown of Perception

Most of the accent so far has been on the presence or absence of a simple stabilized test object, such as a straight line. Here it was found that the line disappeared and reappeared in a unitary all-or-none fashion, there being no partial disappearance or slow fading. One might now well ask what happens when more complex stimulus figures are stabilized. Do they disappear and reappear in part or whole, and, if in part, is there any underlying organization in their behaviour which might be related to their configuration?

Answers to the above questions are to be found in the studies reported by Pritchard, Heron and Hebb (1960) and Pritchard (1961b), who used a contact lens/collimator system developed by Pritchard (1961a) to stabilize targets varying in shape and complexity. It was found that complex stabilized figures disappeared and reappeared in part or whole, and from their observations they formulated a set of 'rules' which the figures seemed to obey.

(a) Unitary action of straight lines: Even though a straight line may extend over the whole of a 2^{o} field, it will tend to disappear and reappear as a whole. However, if the line does break up, the break is most likely to occur at a point of intersection with another line. The straight lines, comprising the outline of figures such as a triangle, square, cube, etc., tend to act independently, thus supporting the Hebbian notion of cell assemblies corresponding to simple perceptual units. The exception is that lines which are parallel to each other tend to act together, this occurring in three dimensional, as well as two dimensional, figures. When the target consists of, say, rows of squares, there is evidence of linear organization, in that the figure usually disappears leaving one whole row visible, which may be horizontal, diagonal or vertical, the horizontal usually being predominant, this confirming the predictions concerning similarity and contiguity of Gestalt theory.

(b) Visibility as a function of complexity and meaningfulness: In general, the more complex a figure is (in terms of the number of elements), the longer some part of it will remain visible, but this is in part also determined by its meaningfulness, as a meaningful figure is visible longer than a meaningless one. In a target consisting of two curves, which are similar apart from the fact that one is a recognizable profile of a face, the profile of the face is visible much longer than the meaningless curved line. A monogram, consisting of the letters H and B, also appears to emphasise the importance of past experience, as it breaks down into recognizable letters and numbers, i.e. H, B, 3, 4, and a word such as BEER breaks down more often into common words such as PEER, PEEP, BEE, BE, rather than, say, EER, EP, etc. (obscuring lines drawn over a meaningful figure tend either to fall into a plane behind it, or to disappear more often). It is interesting to note that even a figure consisting of many meaningless curlicues first comes and goes in random sequence, but soon small groups of these curlicues become organized into recognizable patterns which then behave as units, thus suggesting that they themselves have become meaningful perceptual elements. The above findings lend support to the Hebbian notion of past experience building up cell assemblies into phase sequences, which in this instance correspond to more complex perceptual entities. According to Milner (1957), this is not achieved by the cells of one assembly acquiring connections with cells of another, but by cells sensitized by the first assembly becoming incorporated into the second: when newly added cells are mainly primed by sensory input, then perceptual learning results, but if they are primed by the firing of another cell assembly, then associative learning takes place. However, the Gestalt concept of perception being wholistic in nature also receives some support.

(c) <u>Visibility as a function of the smoothness of the figure</u>: Smooth figures tend to be much more stable than jagged ones, which disappear and reappear with much greater frequency. The 'good' figure (Koffka, 1935) is much more likely to act as a whole than a poor figure, a circle being relatively stable compared with other configurations, even a comparable ellipse (Evans, 1965b). There was also evidence of the Gestalt notions of regularization and symmetry, whereby, say, an amoeboid figure with a relatively long bulge would disappear and tend to reappear with a shortened, more symmetrical bulge. It was also found that there was a tendency for completion of incomplete figures, though the filled in lines would appear fainter than the original ones, thus further strengthening Gestalt perceptual theory.

(d) Field effects: The presence of a figure in one part of the stabilized visual field markedly modifies the activity of neighbouring parts of that figure. If the target consists of a triangle and a nearby circle, they may fade as units, leaving either one or the other in view, but when there is partial fading a side of the triangle may remain in view along with a parallel segment of the circle. This effect, along with the tendency of parallel lines to act together (mentioned above), seems to suggest the existence of the "field effect" of Gestalt psychology.

(e) The disappearance of solid tone figures: According to Pritchard (1961b), the fading of a solid tone square starts in the centre and the sharply defined corners disappear one by one. Here, it is the corners or angles which act as perceptual units and not the line edges of the square: the corners are either present and clearly defined or absent. Hebb (1963) points out that this activity shows that gradual fading can occur, thus strengthening the idea that the all-or-none disappearances and reappearances of the other figures is due to the failure of a system or systems.

So far the observations have been of a qualitative nature, but Evans (1965b) reports some systematic quantitative measurements on stabilized visibility as a function of shape, and the structured versus random disappearances for a particular figure. Using a full-size haptic contact lens and a miniature attached projector system, targets having an average visual angle of 5^{o} were presented to the subject. The basic figure was a linear circle, to which was added a vertical, and then a horizontal diameter line. Significant increases in the percentage disappearance times (disappearance of part, parts or the whole of the image) were found between the figures in the above order, there being no significant change in the disappearance time of the inscribed + when rotated through 45^{o}.

Clearly perceptual stability was related to shape, possibly just a function of length of projected line. However, a capital A, having a projected length of line slightly less than the circle, was found to have a percentage disappearance value of almost double that of the circle. It was then thought that the instability of 'spiky' figures observed by Pritchard et al. (1960) might provide an answer, so a Z and an S, equated for length of line, etc., were used, the hypothesis being that acute angles were a factor in provoking high disappearance values. Although the results were as predicted, familiarity had not been controlled for, so two spiky figures along their equated, rounded counterparts were used, and it was demonstrated that a spiky nonsense figure with intersections was much less stable than an equivalent rounded figure with intersections.

Evans (1965b) also made a quantitative investigation of partial and non-random disappearances of a + inscribed in a circle, and found that, at the most, 75% of the effects were random, while less than 10% were unitary (whole figure), the rest being structured (segments bounded by intersections). The three subjects used showed a very high measure of agreement, and Evans mentions that the breakdown of other targets reveals that these propositions alter with change in pattern, though seldom dramatically.

A more detailed investigation of the field-effect found by Pritchard _et al_. (1960) has been made by Cohen (1961) and Tees (1961). Cohen (1961) presented a vertical stabilized line (2' of arc in width) to the right eye of the subject and a parallel, unstabilized line to the left eye, the angle of separation between the two lines being varied by the subject fixating one of three points to the right of the unstabilized projected line. Using separation distances equivalent to 25, 75 and 150 minutes of arc, it was found that the visibility of the stabilized line was inversely proportional to its distance from the unstabilized line. Tees (1961) investigated the effects of a straight line on four configurations at three distances of separation: 30, 90 and 120 minutes of arc, both the line and configuration being stabilized in the same target. It was found that the independence of the line from the configuration was not only directly proportional to their separation distance, but was also a function of the shape of the configuration; in configurations with lines parallel to the variable line, fragmentation-to-parallelism increased as the separation distance decreased. That the increase in simultaneous activity between stimuli whose separation distance decreases is not solely due to Gestalt field effects, is apparently shown by a fifth target used by Tees (1961), which consisted of two vertical parallel lines with a 45° diagonal interposed between them. An analysis of the disappearance/reappearance frequencies of the various elements of the figure revealed that the two parallel lines were seen together 49% of the total viewing time, while the diagonal plus either of the two parallels, was seen for only 30% of the time. A field effect extending from the one parallel line to the other should have a greater effect on the intervening diagonal. As this was not found, it must, therefore, be assumed that the related activity of the parallel lines is only partly due to a field action.

It is, at this point, worth noting that Evans and Piggins (1963) found that the fragmentation of geometrical shapes, when viewed under conditions of steady fixation, was very similar in type to that obtained when they were viewed using a contact lens/collimator stabilizing system. The effects, however, were less dramatic under the former condition, where they were centrally fixated at two distances (6 m. and 2.5 m.), the targets subtending 2° and 5° respectively, and were illuminated at 8.5 or 0.2 foot candles (91.5 or 2.2 lux) at 6 m., and 0.2 foot candles (2.2 lux) at 2.5 m. Comparable results were also obtained by McKinney (1963), who painted large-scale versions of some of the figures from Pritchard, Heron and Hebb (1960), in luminous paint, and found that when these were fixated in darkness, they fragmented in a very similar manner to the stabilized images of Pritchard et al.

3.3. Resume

A black line on a light background disappears in a few seconds, this time being an inverse function of its width and background intensity. Visual acuity would appear to be mainly based on the spatial pattern of retinal illumination, eye-movements serving to overcome the loss of vision which would occur under invariant retinal stimulation. The optimum rate of flicker, either of the field or of the object against the field, required to sustain visibility of a stabilized target is under 5 c.p.s., while the optimum type of induced movement required for maintaining perception of a stabilized object, appears to be one having a low frequency, but a high amplitude.

The disappearance/reappearance phenomena of simple stimuli are found to be a function of the degree and type of stabilization deployed, certain methods being prone to numerous artifacts. The visibility of a stabilized image also depends on stimulation of other sensory modalities, area of attention and type of contralateral visual stimulation. Stabilized coloured objects tend to desaturate first, leaving only a brightness difference, which soon becomes a homogeneous grey. When an object moves within a stabilized field, there is a tendency for the differences between them to be conserved. Also, under stabilization, contrast thresholds have been found to be much higher than normal for the same level of brightness.

The organization of the breakdown of visual perception under conditions of stabilization gives support to both Gestalt and Hebbian theories of perception. There is often unitary activity of straight lines, there being both partial and complete disappearance and regeneration of complex figures, their visibility being a function of degree of complexity, meaningfulness and 'goodness' of figure. Field effects appear to exist between stimulus elements, their extent being not only a function of separation distance but of orientation. However, there is fading out of solid tone figures, angles rather than line edges being more stable.

4. INITIAL THEORETICAL CONSIDERATIONS

4.1. The Purpose of the Present Study

4.1.1. Vertical parallel line interaction as a function of separation distance

4.1.2. Vertical parallel line interaction as a function of foveal placement

4.1.3. Line interaction as a function of orientation

4.1.4. Line stability as a function of orientation

4.1.5. Resume

4. INITIAL THEORETICAL CONSIDERATIONS

From section 3.2. concerning the organization of the breakdown of perception, it can be seen that there are two main theories of perception, which receive support from the findings on stabilized retinal images. The elder is the Gestalt theory, which, as it stands today, is basically a distillation of the writings of Köhler (1929) and Koffka (1935), the other being that of Hebb (1949, 1959). A comparison of the predictions of the two theories, and how they match up to the experimental findings is given by Pritchard, Heron and Hebb (1960), Pritchard (1961b), Hebb (1963) and Heckenmueller (1965). As has been mentioned, the holistic 'good figure' approach of Gestalt psychology receives considerable confirmation but does not explain the independent action of parts of even good figures, this aspect being better covered by the Hebbian notion of cell assemblies and phase sequencies, the latter corresponding to more complex configurations of perceptual elements, which have been synthesised by past experience. The finding that the part of the target under attention is more stable than the rest, lends support to that aspect of Hebbian theory which states that "attention is a supporting facilitation from other assemblies" (Hebb, 1963, page 18), while the fact that a meaningful object is visible longer than a meaningless one, is due to meaning in his theory being "activity in a set of inter-connected assemblies, which, as a more complex system, can be active longer" (page 18).

According to Hebb (1963), the findings on fragmentation of geometrical forms, indicate that the activity of a number of separable systems is involved, the localization of which would appear to be outwith the sensory projection areas, thus categorizing them as mediating rather than sensory processes. The finding that a straight line disappears in a unitary fashion cannot be due to simultaneous fatigue in innumerable functionally independent cells, nor can it be due to small localised areas of 'satiation' as hypothesised by Kohler and Wallach (1944) in their explanation of certain figural after-effects. That the locus of the effect is central rather than retinal, receives support from the previously mentioned findings of Krauskopf and Riggs (1959) and Cohen (1961) on inter-ocular interaction.

However, both theories do have difficulty in explaining certain of the experimental findings. Hebbian theory would predict that angles, as well as lines, would behave as separate elements when complex figures fragment, but could not have predicted that retinal stabilization would, in itself, be sufficient to cause the breakdown. Nevertheless, angles rather than line edges are more stable when a solid figure (such as a square) fades, though Hebbian theory cannot, as it stands, easily account for the gradual fading of solid figures. Hebbian theory also has difficulty in explaining certain completion phenomena such as the filling in with finer lines of, say, the vertices of an incomplete triangle. Gestalt theory, however, also has its difficulties, as the often demonstrated field effects have been shown to involve not only proximity, but angle of orientation (Tees, 1961), the latter being a more powerful determinant of the duration of stabilized vision: even the 'perfect' circle does not always fragment in a unitary fashion, as would be predicted by the Gestaltists. It would, therefore, appear that both Gestalt and Hebbian theory must be utilized in attempting to interpret visual perception under stabilized conditions, the Gestalt theory being more applicable to the molar aspects, while Hebbian theory is more useful for a detailed analysis of the constituent parts. Thus, from the foregoing discussion, the two theories would seem to be complementary (rather than contradictory) to the partial explanation of stabilized retinal image phenomena.

4.1. The Purpose of the Present Study

From chapter 2. and section 3.1.4., it can be seen that some of the phenomena reported were probably due to artifacts inherent in certain techniques, contact lens slippage perhaps being the most likely. Heckenmueller (1965) suggests that the results of investigations using such techniques are not invalidated but "must be considered as an expression of reduced image motion instead of stopped image motion" (page 166). Such a simple dichotomy is unfortunately not very helpful, there being a considerable body of evidence (which has already been cited) to suggest that contact lens slippage is far from being the sole determinant of the regeneration of a stabilized image, thus some regenerations using contact lens techniques were not due to slippage.

As has been mentioned in section 2.1., techniques which imaged internal ocular structures, although not liable to 'slippage', were limited solely to these structures: the only remaining technique which gave some choice as to the type of target stabilized and was not prone to 'slippage', was that of flash after-imagery. For these and other reasons referred to in section 2.4., it was decided to use this technique in order to make a systematic study of simple, foveally stabilized linear configurations, bearing in mind that the problems concerned with the comparison of such after-images with stabilized retinal images, resulting from invariant external vision stimulation, will have to be given detailed consideration in order to put the findings into the context of recent work on conventionally stabilized images, using a constant stimulus input.

In brief, these problems (as related to the present study) are a) the consequences and nature of the inhibition of the after-images by eye movement; b) the nature of the relationship of the after-images to more conventionally stabilized retinal images, and c) the possible locus of the phenomena found in the present study of after-images (in relation to those found under stabilization with constant stimulation). The four closely related topics, which were chosen for investigation, will now be listed, along with a brief outline as to what each study hoped to achieve.

4.1.1. Vertical parallel line interaction as a function of separation distance

Reference has been made to Cohen's (1961) finding that when one had a stabilized line in one eye, and an unstabilized line in the other, the stabilized line was visible for longer than when viewed alone: the closer the two, in terms of retinal angle, the greater the effect. Hebb (1963) indicates that the same general result is obtained when both lines are stabilized, but gives no indication as to the source of this finding (presumably one of his own research teams at McGill University), nor does he give any systematic quantitative data on the extent of the effect. Due to the above, it was decided to make a quantitative investigation of this phenomena, utilizing two stabilized vertical parallel lines, varying only in separation distance: qualitatively it was predicted that as the lines became closer together there would be an increase in simultaneous visibility and change frequency, with a corresponding decrease in single activity.

In conjunction with this topic, it was decided to make a small supplementary investigation into (a) subject 'trend reliability' as related to introversion/extraversion (E) and neuroticism (N); and (b) the extent of the interaction phenomena as related to level of arousal. It was predicted that: (a) subjects having high E or N scores would tend to give the least reliable trends as the typical extravert is (amongst other things) carefree, easy-going and not always a reliable person, while the typical neurotic is characteristically 'unstable' (Eysenck, 1964); (b) the higher the level of arousal of a subject, the greater would be the extent of the expected interaction effects - at least up to an optimum level (Hebb, 1955).

4.1.2. Vertical parallel line interaction as a function of foveal placement

Investigations to date, concerning simple stabilized linear configurations, nearly always present such figures with a central fixation point. On certain anatomical considerations one might predict that the type of fragmentation which occurs under conditions of stabilization is a function of foveal placement. The point is that the left half of the visual field in primates is projected onto the right half of both retinas, these having their main projections to the right occipital lobe, and it is generally accepted (Duke-Elder, 1961) that this projection dichotomy includes the fovea; similarly for the right visual field. Now Curtis (1940), in recording electrical responses on symmetrical points on the cortex of the other hemisphere in primates, has found that the only area that did not give any response was Area 17 (Visual 1), showing the probable absence of inter-hemispherical connections between these two areas. Therefore, by studying the flash after-images (monocular fixation) of suitably prepared targets (the three stimulus conditions for two vertical parallel lines relative to a central fixation point being (a) equidistant, (b) both to the right and (c) both to the left), one can investigate the effects of symmetrical and asymmetrical retinal stimulation, and of identical stimulation being projected to both occipital lobes as a unit, compared with that projected to either of the two lobes separately. The stability of the lines under these three conditions being dependent on the degree of cortical neuronal intercommunication between hemispheres, versus that within either hemisphere.

4.1.3. Line interaction as a function of orientation

As cited in section 3.2., Tees (1961) studied the fragmentation of a figure resembling a capital N, without the vertices, and found that the two parallel lines were visible together for a considerably longer time than either of the verticals and the intervening diagonal, thus showing that a 'field theory' cannot entirely account for Cohen's (1961) findings on parallel line stability. In order to investigate Tees' (1961) findings more closely, it was decided to study the effects of linear interaction when one line was kept vertical, while another, identical line, was varied in orientation, the central separation distance remaining constant. On the basis of Tees' study one might predict that the duration of the percentage time visible together and the simultaneous change frequency, would be lower for targets containing a diagonal variable line, than for one containing two vertical parallel lines.

With regard to the findings of Hubel and Wiesel (1965) regarding 'higher order, hyper-complex' cells in the cat's visual cortex, which respond to a delimited line stimulus (in a particular part of its visual field) in either of two orientations, 90° apart, and the fact that functionally comparable lower order cells have been found in spider monkeys (Hubel and Wiesel, 1962, 1965), one might, therefore, tentatively predict that in the case where the variable line is horizontal, there would be a close correspondence, in terms of their 'activities' to that when it was vertical.

4.1.4. Line stability as a function of orientation

Data on the activity of single stabilized lines varying in orientation, but whose central distance from the fixation point remains constant, were required in order that a more complete understanding of line interaction as a function of orientation might be attempted. It was predicted that there would be no significant differences between single lines differing solely in orientation, as there was no previous evidence to suggest that orientation, per se, was a determinant of a line's stability: Hubel and Wiesel (1962) found for the cat that there was no predominant orientation to be found among the simple cortical cells, which were excitable by a line stimulus of a certain orientation, in a particular region of the cat's visual field.

It was also decided to examine briefly the effects of flash stabilization on binocular vision and vision with the non-dominant eye. It was thought that in the former instance the image would be slightly more stable than that for the dominant eye alone, while that for the non-dominant eye would be slightly less stable. Horizontal parallel line interaction was also studied for one separation distance, it being predicted that their activities would differ little from those of a corresponding pair of vertical parallel lines.

4.2. Resume

The Gestalt and Hebbian theories of perception have each been shown to be partially capable of explaining some of the stabilization phenomena: however, they are best thought of as being complementary to each other.

To minimise the role of artifacts in a quantitative investigation of simple foveally stabilized linear configurations, the flash after-image technique was utilized. Reasons were given for studying the following topics: vertical parallel line interaction as a function of separation distance, including a small supplementary investigation into introversion/extraversion, neuroticism and level of arousal; vertical parallel line interaction as a function of foveal placement; line interaction as a function of orientation and line stability as a function of orientation. Mention was also made of the necessity of detailed discussion of the relationship of the phenomena found using this technique to those using the continuous stabilization of invariant retinal input.

5. METHODOLOGY

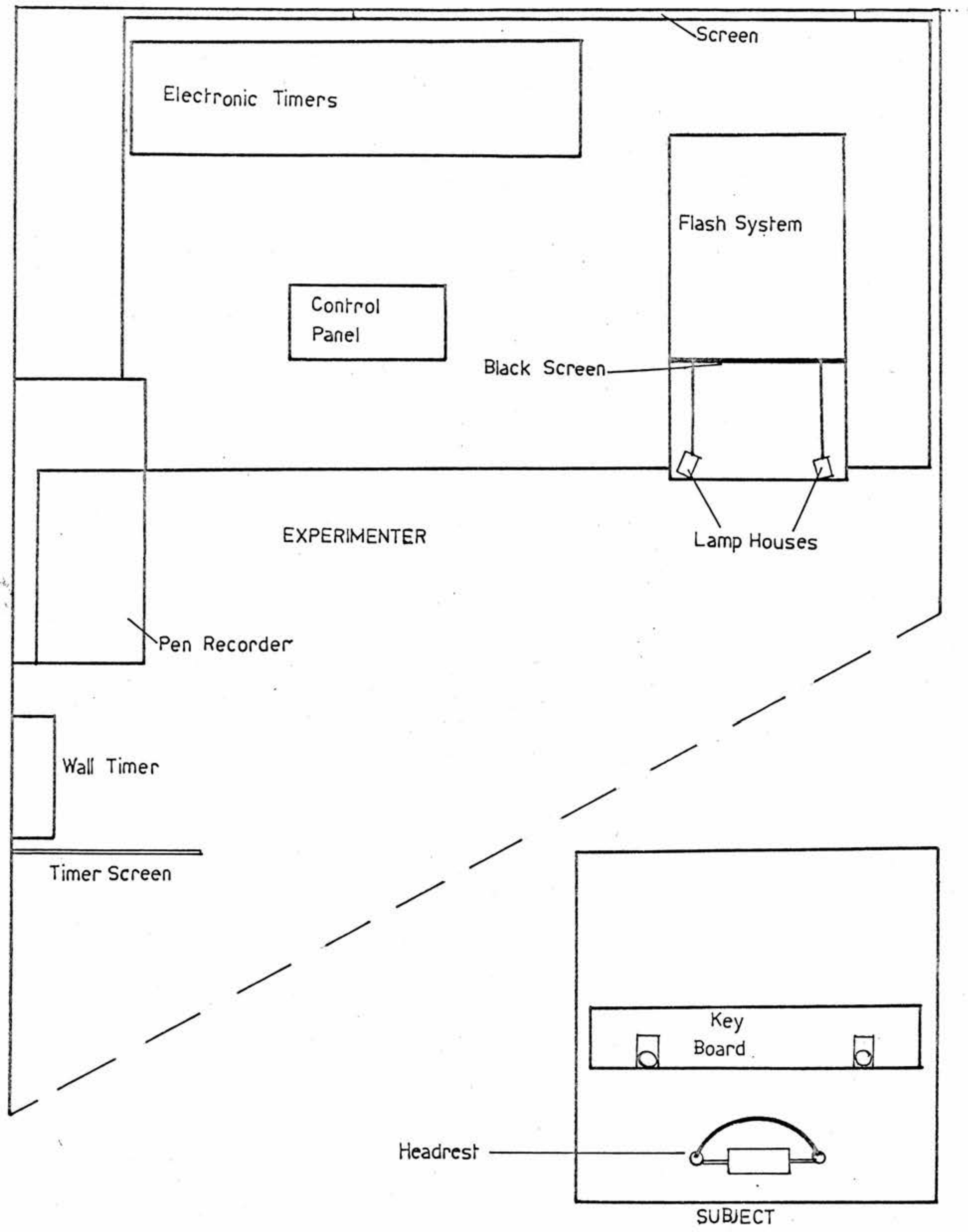

Figure 5.i. Outline sketch of Laboratory: scale 1:10; the distance between the two tables is not to scale.

5. METHODOLOGY

In this chapter, detailed consideration will be given to the apparatus, subjects and procedure, indicating, where relevant, the rationale behind the approach. It should be noted that 'dominant' monocular vision was used throughout the main studies.

5.1. Apparatus

An overall outline sketch of the laboratory in which all the experiments were conducted is given in Figure 5.i. Areas, such as doors, windows and vents, which might transmit external sound, were 'sound-proofed' using heavy felt and sound absorbing tiles. The whole room's interior walls were painted in matt black, as were those items of the apparatus which were in direct view of the subject, both table surfaces being covered in black, matt cloth. The room was kept at a relatively constant temperature of 65° F. by means of a thermostatically controlled convector heater, ventilation being provided by an extractor fan and two inverted U vents, one at each end of the room. The relatively steady noise (46 - 47 decibels) emitted by the extractor fan served to give an almost constant level of auditory stimulation, thus ensuring that any fluctuations in external noise would be very difficult to discern against such a background, the maximum occasional sound level being 50 db. (the above sound energy levels were all measured relative to a reference level of 0.0002 dynes/cm^2, using a General Radio Company sound level meter, whose microphone was positioned by the headrest). This relatively invariant level of auditory stimulation was necessary, as it has already been pointed out that changes in the level of auditory stimulation affect the disappearance and reappearance of stabilized retinal images. The power supply to all the apparatus was stabilized using a Claude Lyons solid state voltage stabilizer (type BTR 2) having an output of 240 volts ± 1.3% r.m.s. from zero to full load. Although this type of stabilizer gives rise to approximately 6% harmonic distortion, this was not of material consequence for the type of electrical equipment utilized.

5.1.1. Foveal flash system

The source of the flash was an inverted U-shaped Xenon tube, emitting a flash of 10^{-3}* seconds duration, having a colour temperature of 5600 K*, and a power rating of 135* joules (more detailed information as to the flash emitted by the target apertures is given in the appendices, section 10.1.). The flash head and its power supply were manufactured by Braun (Frankfurt), the model being the Automatic EF 3. The Xenon tube was mounted vertically and positioned at the point of intersection of the radius of curvature of a 10.5 cm. diameter concave mirror (having a radius of curvature of 9.8 cm.)

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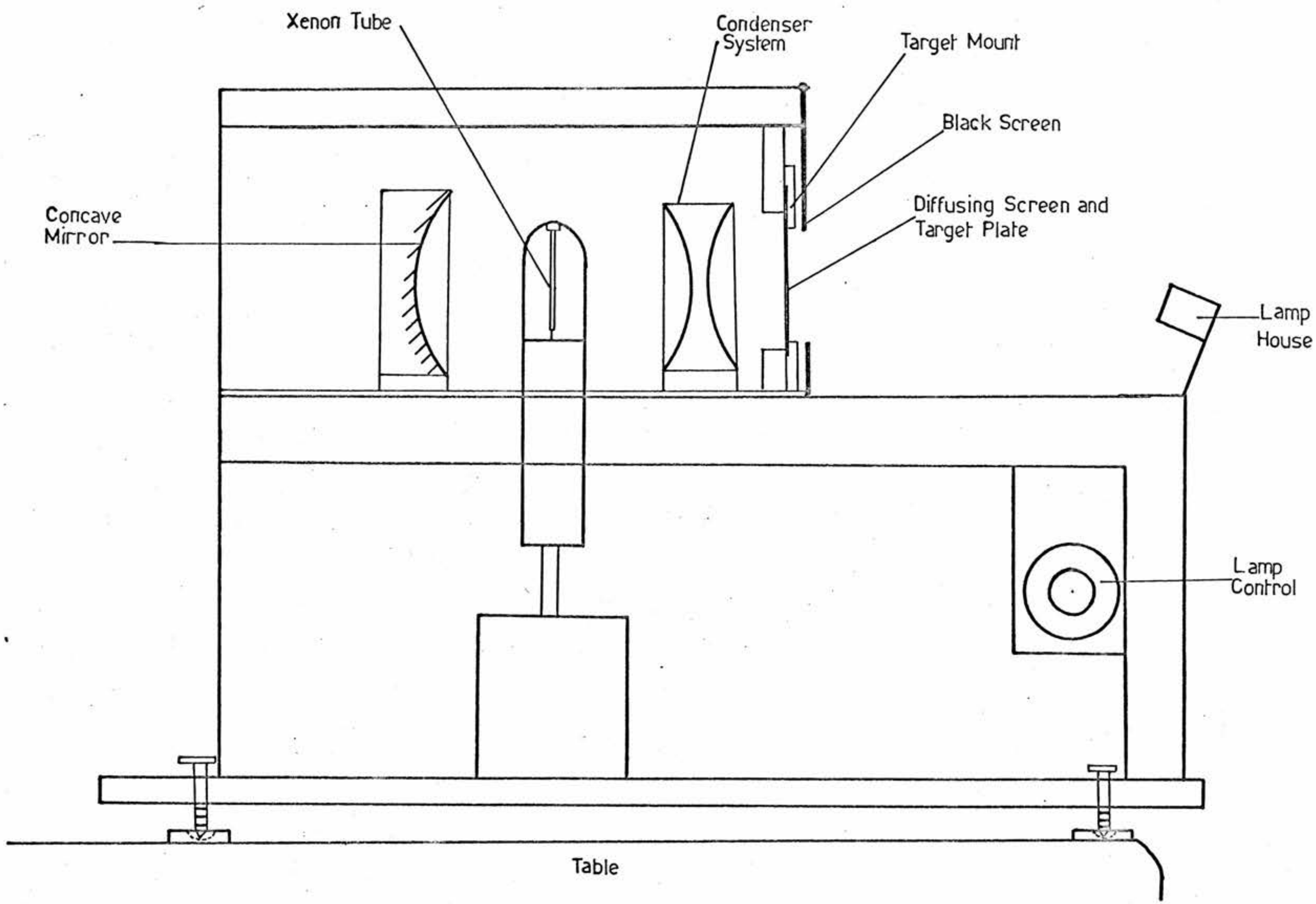
* Manufacturer's values.



<u>Figure 5.ii.</u> Foveal Flash System; scale 1:4.

and the focal point of a 10.2 cm. diameter double plano-convex condenser system having a focal length of 7.2 cm. (Figure 5.ii.). The concave mirror produced a U-shaped image, which, when superimposed on the inverted U tube, gave rise to an annular flash source, and this was converted into a parallel flash beam by means of the condenser system. This parallel beam was then passed through a Johnston's diffusing screen (which was positioned 3.2 cm. in front of the condenser system), and whose transmission homogeneity, as measured using a bridged spectrophotometer with a measuring aperture of 7.5 mm. diameter on random spot comparison areas, did not vary by any more than ± 0.6%.

The mirror and condenser system were mounted on steel rails and guide bars, and when correctly positioned they were bolted down. The Xenon tube was adjustable in height and tilt (relative to the mirror and lens system) and was so aligned as to produce an annular image. The flash projector was mounted on four steel bolts, which fitted into recessed brass plates screwed to the experimentor's table, this being bolted to the concrete floor.

5.1.2. Target plates and mount

The targets were 11 x 9 cm. brass plates, having a thickness of 0.59 mm. Slots, measuring 30 x 2 mm. (i.e. subtending 51.5' x 3.43' of arc at 2 m.) with rounded ends, and varying in orientation and proximity to the central fixation spot, were milled in these plates. The facing surface of each plate was

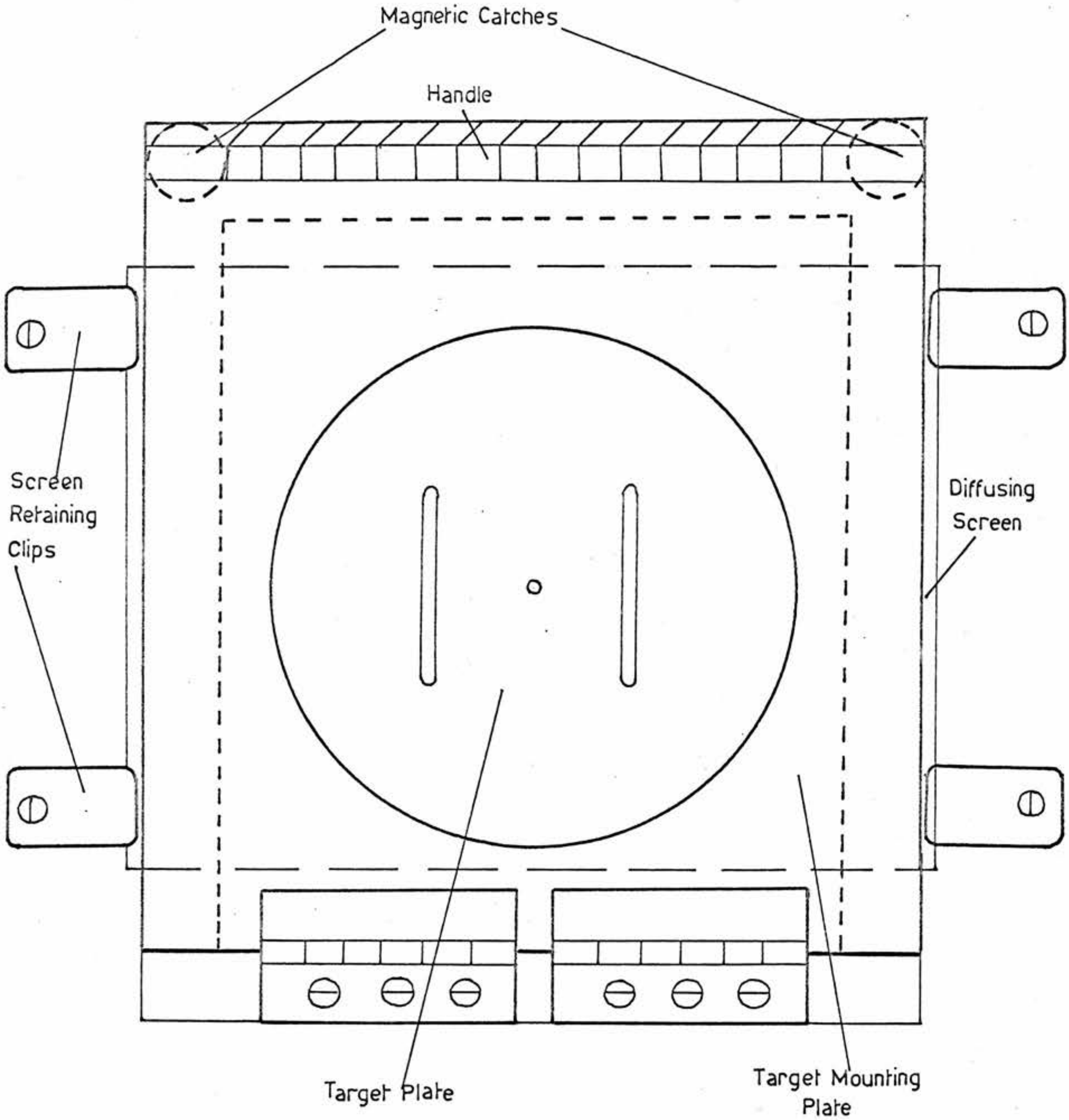


Figure 5.iii. Target Plate Mount; ~ to scale.

coated with matt black spray paint, while the inside surface of each slot and 1 mm. of the facing edge to the slot was coated with an alcohol-based black dye. A white spot, 2 mm. (3.43' of arc) in diameter, was used as the fixation point, its position normally being equidistant from the centre(s) of the slot(s). Due to the reasons mentioned in section 2.4. all the stimulus configurations lay within a circular area subtending an angle of well under 2° of arc (Polyak, 1957, estimated that the rod-free area of the fovea subtends an angle of $1^{\circ}40'$ to 2°), the majority lying within $1^{\circ}40'$. The target plate was mounted flush against the diffusing screen by means of a brass plate hinged at its base, and secured in position by means of two magnetic catches, there being a 77 mm. diameter opening in the plate (see Figure 5.iii.).

5.1.3. Illumination of pre-stimulus fields

At a distance of 1.2 cm. in front of the target holder, and hinged from above, there was a 31 x 17.5 cm. (i.e. subtending 8.87° x 5.9°) black felt covered panel with a 7.4 cm. (2.12°) central aperture (see Figure 5.ii.), over which, for adaptation purposes, there was placed a removable piece of black felt. This screen was illuminated by means of two lamp houses containing matched (2.5 V; .3 A) bulbs connected in series with a variable resistor (which was attached to a precision-geared control knob) and fed by a 3 volt transformer. In front of each bulb there was placed a 25 x 4 mm. diameter disc of milk plastic, the lamps being adjusted to produce uniform illumination of the target area. The brightness values (as measured by an S.E.I. photometer) of the adaptation screen, and the actual target surface were $\bar{2}.0$ and $\bar{2}.2$ log foot Lamberts (0.034 and 0,054 cd/m^2) respectively.

There was also an 83.5 cm. x 134 cm. matt black screen behind the apparatus, which was used as an inter-trial visual field, this being illuminated by a carefully shielded room light, the screen's brightness being 1.2 log foot Lamberts (0.53 cd/m^2).

5.1.4. Position of subject

The subject was seated behind a table (see Figure 5.i.) which was bolted to the concrete floor, his head being vertically positioned by means of a head and chin rest such that the distance from the target to his eye was 2 m., the positioning error being ± 0.25%.

5.1.5. Recording apparatus

The subject recorded the presence or absence of the bar after-images by means of two dual-function keys, set on a moveable board (see Figure 5.i.). These were connected to 3 Electronic (Model SC1) Advance counter timers, such that for a two bar after-image, the time visible for each bar was obtained, along with the time for which they were visible simultaneously. The keys also operated individual pens in a six channel Behaviour apparatus pen recorder (having a paper speed of 28 mm./min.), thus giving a continuous record (see

Appendix 10.2. for an example) of the activity of the after-images (depression of a key, therefore, moved its corresponding pen and stopped the count on both its corresponding timer and the one recording simultaneous visibility); another pen recorded the instant at which the flash was fired.

5.1.6. Control panel

This consisted of a three position multifunction switch, which in the resting position left the target lights on; position two fired the flash tube, extinguished the target lights and initiated the flash marker; while position three initiated the electronic timers. In practice the knob was quickly moved from position one to position three, there being a delay of only a few hundredths of a second between the firing of the flash and initiation of the timers. There was also a switch, which disconnected the flash circuit for the purpose of resetting the multifunction switch, and another coupled to the flash marker channel. This switch could be used by the experimenter for marking points on the record which had to be altered at a later date, due to, say, accidental depression of a key or keys by the subject during a trial run.

5.2. The Subjects

Of the 72 subjects used in the main study, 46 were psychology students, 23 were physics students, while the remaining three were students outwith the University, the age range being 19 - 27, but all except three were in the 19 - 23 range. The ratio of males to females in the sample was 7:5.

All of the subjects were visually screened using a Bausch and Lomb Ortho-Rater, which checked the following: far and near acuity and phoria, depth and colour. Of the total of 95 subjects tested, 18 failed the visual tests, the remaining 5 being 'fallouts' from the main experiments. The criteria for selection of a subject was a score of 9* or over (for both near and far acuity) in the 'dominant eye', as measured over three trials using a Miles (1930) tube. Fifty-one of the subjects had a dominant right eye, 18 had a dominant left eye, while the remaining 5 showed equal dominance, and these subjects used whichever eye they preferred for fixation purposes.

5.3. The Experimental Design

There were four experimental sessions for each subject, each having a duration of just under one hour. The length of the intervals between sessions was rather variable, mainly being a function of the subject's availability, and varied from one day to two weeks, the usual duration, however, being one week. On each experimental session the subject was subjected to four flashes (see Figure 5.iv.), details of which

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* A score of 9 on this scale is equivalent to 20/22 vision in Snellen notation (Kuhn, 1950, p. 110).

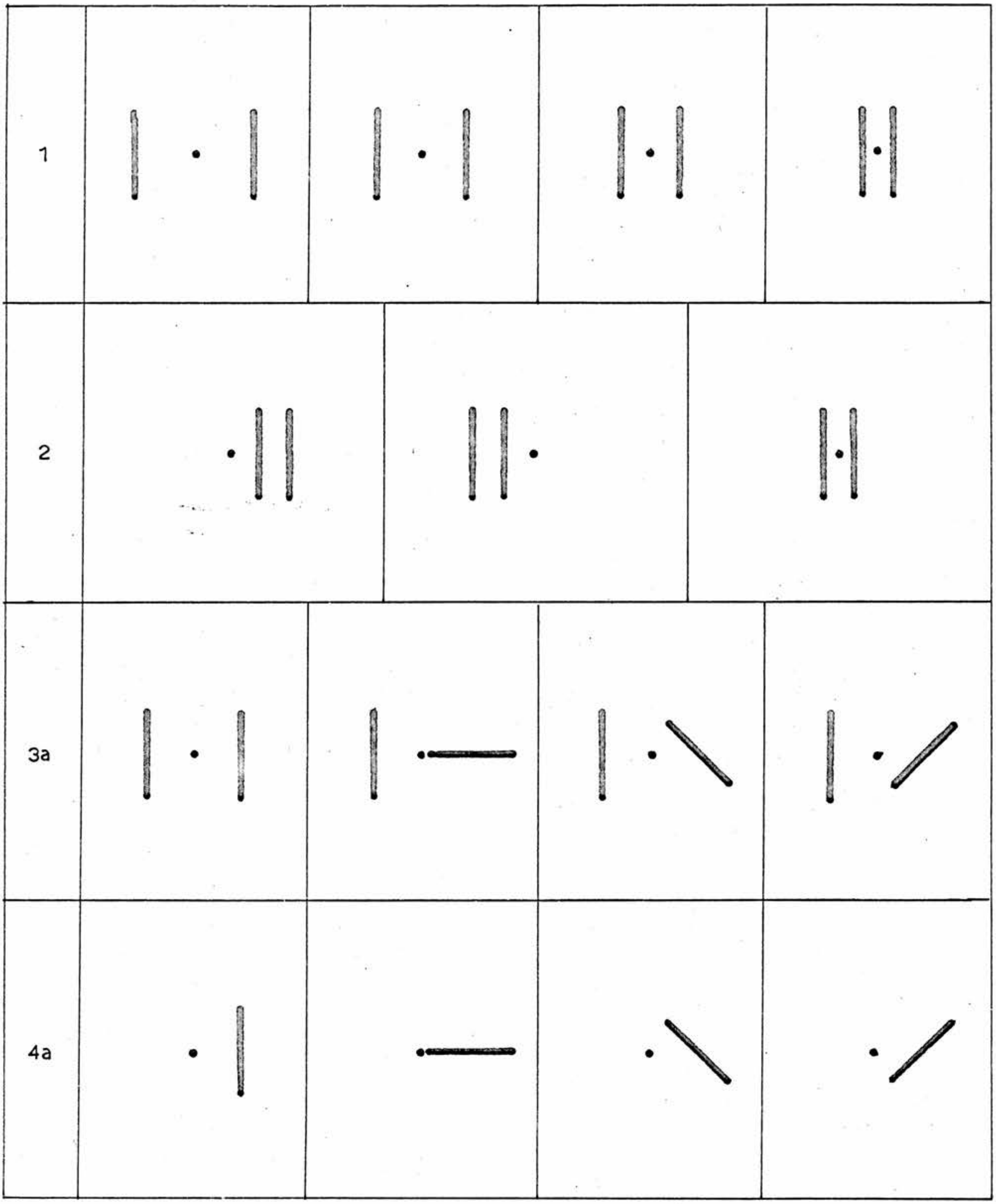

Figure 5.iv. Target configurations used in the present investigations: scale approximately 1:2, the black dots representing the white fixation spots.

are listed below:

1) Two parallel vertical bars at four central separation distances apart, namely: 40, 30, 20 and 10 mm. (i.e. subtending 68.7', 51.5', 34.3' and 17.2' at 2 m.), the fixation spot being centrally positioned.

2) Two parallel vertical bars, having a central separation distance of 10 mm. (i.e. subtending 17.2' at 2 m.), and three positions relative to the fixation spot, namely: 10 mm. to the right, 10 mm. to the left and equidistant.

3a) Two bars, the right one being in one of 4 orientations (vertical, horizontal, 45° to left and 45° to right), the left one remaining vertical, the central separation distance in all cases being 32 mm. (i.e. subtending 54.8' at 2 m.).

3b) As 3a, but with the left bar varying in orientation, the right bar remaining vertical.

4a) One bar in one of 4 orientations (vertical, horizontal, 45° to left and 45° to right), 16 mm. (i.e. 27.4' arc at 2 m.) to the right of the fixation point.

4b) As 4a, but with the bar to the left of the fixation point.

Of the first 48 subjects, half performed the sessions in the order 4a, 1, 3a and 2 while the remaining half performed them in the order 4b, 1, 3b and 2. Of the remaining 24 subjects, half performed the sessions in the order 3a, 1, 3b and 2, while the remaining half performed them in the order 3b, 1, 3a and 2. Within each session, the order of presentation of the stimulus flashes conformed to a random block design, whereby each stimulus configuration appeared with a frequency of 1 in 4 in each of the four possible presentation positions. Thus, for the subject group as a whole, any serial order interaction effect would be evenly distributed over the four contingencies.

The plate used for session 2 was the 10 m. central separation plate of session 1, this, however, having an additional fixation spot placed 10 mm. away (centrally) from one of the bars. The change in position of the fixation spot (to the right or left) being effected by rotating the plate through 180°, the fixation spot not in use being covered by means of a matt black paper overlay.

The single bar used in sessions 4a and 4b were those of 3a and 3b, but with the vertical bar covered by means of an opaque matt black overlay.

5.4. <u>The General Experimental Procedure</u>

1) Once the subject (S) was seated, he was told the outline of the experimental procedure. In addition, he was given a brief description of the probable course of the after-images (i.e. initially bright white, but gradually diminishing in intensity with possible fluctuations in colour, ending up as black bars against a greyish (visual noise) halo, all these phases being classed as 'visible after-images'). An indication was given as to the possibility of disappearance and

reappearance of either or both of the bar after-images, whose disappearance was to be recorded by means of depressing the corresponding key, releasing on reappearance. It was also mentioned that the appearance of the after-image after the flash might be delayed by a 'blank' or a diffuse white patch, and, if so, indication of this was to be given by means of the keys.

Emphasis was given to the fact that careful fixation of the white spot was required, that the operation of the keys should be quite positive, and that any mistakes in key operation should be mentioned briefly at the time so that their position could be marked on the pen record by the experimenter.

2) The chin rest was adjusted to a height such that the upper edge of the eye sockets were ¼" below the lower edge of the head band.

3) The subject placed the eye patch over his non-dominant eye, put his head in the head rest, and adjusted the key panel to a comfortable distance in front of himself.

4) The pen recorder was started and the main light extinguished, this being followed by two minutes 'foveal adaptation', the subject monocularly viewing the dimly illuminated adaptation screen.

5) The adaptation screen was removed, revealing a circular aperture through which the fixation spot was visible.

6) S was asked to focus on and to fixate the small white spot.

7) Between 2 and 3 seconds later, the flash was fired, the marker pen activated, the target illumination extinguished and the electronic timer(s) started.

8) Recordings of the A.I. activity were made by the subject operating the pen recorder keys (depression signifying disappearance). Thirty seconds grace was given after the subject was of the opinion that the after-image(s) had finally disappeared, just in case the A.I. should reappear.

9) The timers were 'locked', S then being asked to release the keys; the main light was switched on, and S was allowed to remove his head from the headrest. For the remainder of 10 minutes (see section 5.4.1. for rationale), measured from the firing of the flash, S was requested to keep his gaze within the large matt blackboard behind the apparatus, and was questioned about the activity of the after-images. The target plate was also changed.

10) S put his head back into the headrest and the procedure was repeated as from heading 4.

The main reason for questioning the subject after each run was to ensure that he was performing the reporting procedure correctly. However, it also gave the experimenter an opportunity to ascertain how marked the after-image drift was, and helped to reduce possible boredom during the remainder of the required cone regeneration time.

The majority of the first 48 subjects had previously completed form A of the E.P.I. (Eysenck Personality Inventory; Eysenck, 1964; see Appendix 10.3.) for another project, while the few from this group who had not completed the questionnaire did so after one of the experimental sessions. The remaining 24 subjects had an approximate measure of their level of arousal taken by means of counting the number of perspective reversals of a 12.5 cm. sided Necker cube (Hebb, 1955, 1958; Sherwood, 1965), consisting of 1.5 mm. black lines drawn on a white card, viewed at a distance of 2 m. This was performed for one minute at the beginning and end of session two, the 'arousal score' being the mean number of perspective reversals.

5.4.1. Cone regeneration times

Hecht, Haig and Wald (1936) found that the threshold for a centrally fixated 2^{o} field remained practically constant after two minutes, the dark adaptation run being preceded by two minutes light adaptation to a brightness of 300 ml. (954.9 cd/m^2). Hecht, Haig and Chase (1937) found that 2 minutes light adaptation to a 30^{o} field having an intensity of 400,000 photons (which are equivalent to trolands) gave rise to a dark adaptation curve whose cone activity ceased after just over ten minutes. Crawford (1937), using a 45^{o} pre-adaptation field varying in brightness from 1.55 c/ft^2 - 132 c/ft^2 (16.7 - 1420.9 cd/m^2) and having a duration of five minutes, found that the foveal dark adaptation curves had levelled out after twelve minutes, the test spot being a central 0.46^{o} diameter disc.

The above three findings indicate that foveal regeneration would seem to be complete within 10 minutes or so, the actual time being a function of the brightness of the pre-adaptation field. Perhaps the most relevant findings are those of Crawford (1946) where the 12^{o} diameter pre-adaptation field varied in brightness and exposure duration. For exposures of 0.009 second, having a brightness of up to 31,500 c/ft^2 (339066 cd/m^2), the thresholds for a central foveal test field, subtending an angle of 0.5^{o} at the eye, all levelled out before 100 seconds had elapsed.

As an actual check on the cone regeneration times under the experimental conditions used in the study, the following test was performed. The flash produced by the apparatus was emitted through a circular aperture, subtending an angle of 2^{o} 12'. Two dark adaptation curves for the centrally fixated flash field were determined using a Goldman/Weekers Adaptometer, with a 2^{o} centrally fixated test field, and these showed that the required adaptation level of $\overline{2}.0$ log foot Lamberts (0.034 cd/m^2), equivalent to the brightness of the pre-flash adaptation field in the main studies, was reached in well under five minutes.

In view of
Due to the above considerations, twelve minutes was regarded as being a sufficiently long period of time to allow an effectively complete return to equilibrium of the cones

stimulated by the flashed target configurations.

5.5. Resume

A suitably prepared darkroom, with an extractor fan which provided a relatively uniform auditory background, was used as the laboratory. The apparatus consisted of a Xenon flash tube set between a concave mirror and a condenser/diffuser system, so positioned as to produce a uniform flash patch, against which were placed different target plates, having identical slots but these varied in position and orientation. A total of 72 visually screened students appeared at four separate sessions, each containing four 'flash runs'. After a 2 minute adaptation period, each S fixated the target with his dominant eye and received a flash stimulus configuration, which resulted in an after-image, whose 'activity' in total darkness was recorded by means of keys coupled to recording pens and electronic timers. The order of presentation of the stimuli conformed to a random block design. To allow for complete regeneration of the bleached cone pigments, 10 minutes was allowed between the initiation of the stimulus flash and the start of the next pre-adaptation period. Measures of extraversion/introversion, neuroticism and level of arousal were also taken.

6. RESULTS

6.1. Data Extraction

Each subject's pen record of the 'activity' of the after-image of the first flash, of each session of four, was discarded. This was to allow for initial mistakes in acquiring the required response procedure, and for sensory motor 'warm up' effects. The following dimensions, for both right and left components of the after-image, were measured (where applicable) from the remaining pen records:

(a) The time from the flash to the last disappearance;

(b) The time from the flash to the first disappearance;

(c) The duration of the first disappearance;

(d) The change frequency;*

(e) The simultaneous change frequency.

The following dimensions (where applicable) were readings taken from the electronic timers:

(f) The time for which each component of the AI was visible;

(g) The time for which both components of the AI were visible together.

The dimensions (f) and (g) were then converted into percentages on the basis of the larger value of (a), the time from the flash to the last disappearance, while the dimensions

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* A change = a transition from the AI being present to being absent or vice versa.

(d) and (e) were converted to percentages on the basis of the total change frequency of the two components. The percentage time that either a right or a left component was visible was then calculated. All of these dimensions were entered onto individual data sheets, from which group data sheets were then prepared for each of the above dimensions apart from (c), the duration of the first disappearance, which was not subject to any statistical analysis. This was due to the fact that when a component of the AI did not disappear and reappear before its final disappearance, no finite value could be attached to it, and the remaining values, because of the nature of the experimental design, would not have been uniformly distributed among the stimulus conditions.

6.2. Data Processing

The group data for each of the dimensions for each experiment was then punched onto data tapes and processed by a program written in Atlas Autocode. The program analysed the data according to a one way analysis of variance and printed out the mean and the variance for each column, the number of degrees of freedom between and within sets, the between and within sums of squares, the F ratio and the standard error of the difference between means (SE_{dM}) - based on the total variance within the sets. The program was also used for ascertaining if there were significant differences between pairs of means, the only modifications required to the print out being when the pairs were mutually dependent percentages. In this case, as the numbers of degrees of freedom are halved, so the value of the F ratio has to be halved, and the SE_{dM} multiplied by the square root of two.

When applying the program as a one way analysis of variance, subsequent testing for significant differences between pairs of means, when the F ratio was significant at or beyond the 0.05 level, was done using a procedure outlined by Guilford (1956). If one can assume that the variances in different sets are relatively uniform,* then one can take the SE_{dM} and multiply it by, say, the $t_{.05}$ value for the number of degrees of freedom within the sets. This product, if it is less than the difference between a pair of means, indicates that the means are significantly different beyond the 0.05 level.

The question as to whether the implicit assumptions inherent in a one way analysis of variance were adhered to in the processing of the data, was given consideration in the light of Hays (1963), who, with regard to the requirement of homogeneity of variance, is of the opinion that no preliminary test to satisfy this assumption is necessary, especially when the numbers of cases in the samples are equal. He also considers that departures from a normal distribution have

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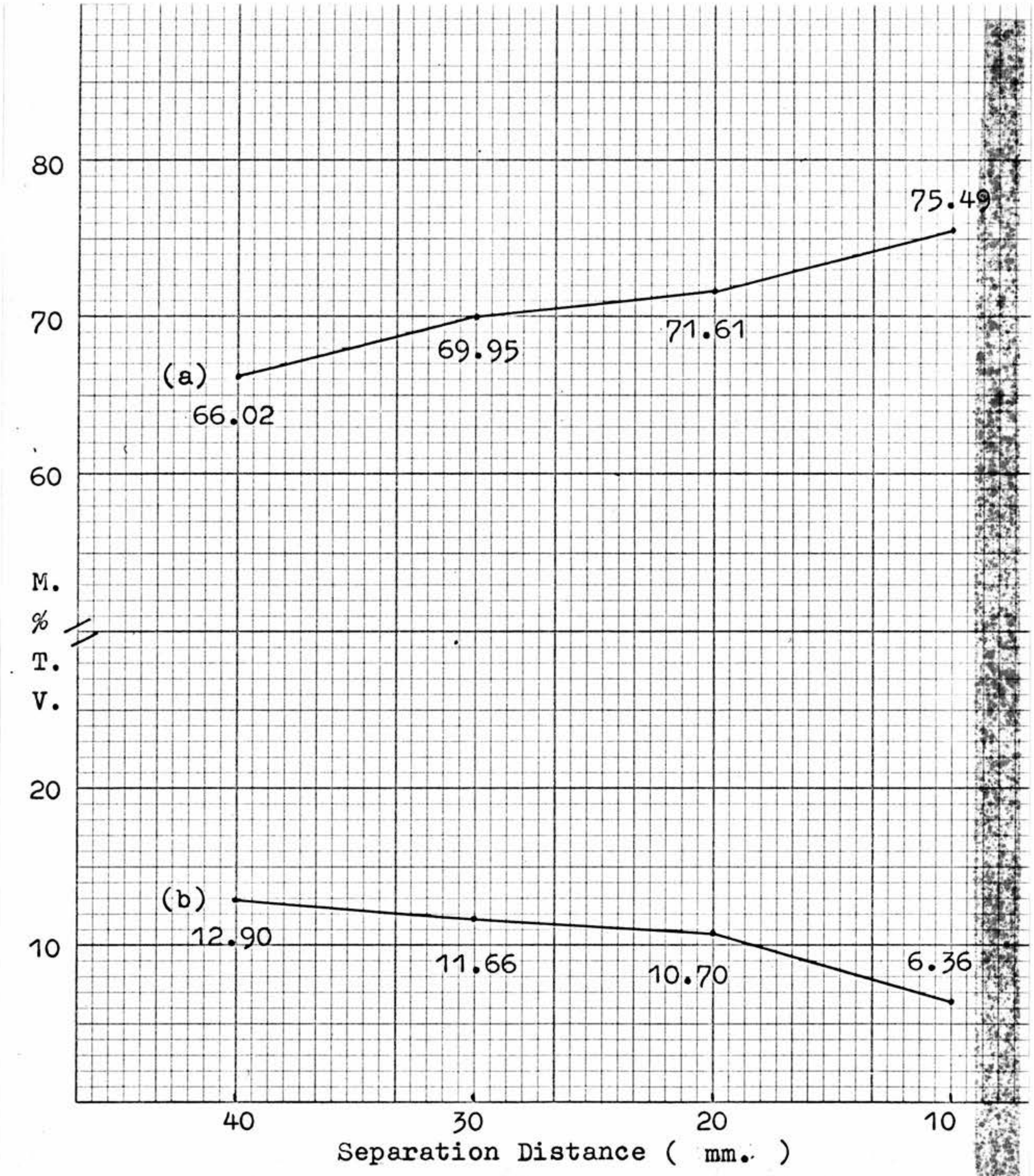
* This was checked by taking the two most divergent cases of within sets variance, forming them into an F ratio, and making an F test with (n-1) and (n-1) degrees of freedom (Guilford, 1965, p. 276).

little effect, so long as the sample size in each case is relatively large. Boneau (1960), after an extensive study of the effects of varying the distribution and variance of the data for 't' tests, concludes that so long as the samples are of equal size and the assumed underlying population distributions are of approximately the same shape, then for samples >15, marked variations in variance (up to 1:4), the true probabilities are quite likely to lie within 0.01 of the nominal value. When the sample size reaches 25 or 30, only extremes of skew will effect the 't' values obtained. He also cites evidence that most of the above applies to F tests in analysis of variance, as the two tests are intimately related.

The requirement that the population distributions should be normal was therefore only adhered to in so far that the group data for each dimension was checked for serious skewness, while the condition of homogeneity of variance between the sets was checked as mentioned above, this perhaps being unnecessary as the sample sizes were equal. When the F test on the two most divergent cases was significant, the levels of significance between the means on subsequent 't' testing was checked using the following procedure. The standard error for each of the means was calculated from its variance, and multiplied by the appropriate 't' value for (n-1) degrees of freedom at, say, the 0.05 level of significance: if the sum of these two products was less than the difference between the means, then the means could be taken as being significantly

Figure 6.i. Graph of the Mean Percentage Time Visible (M.%T.V.) for two Vertical Parallel Lines of varying Separation Distances, visible (a) Simultaneously and (b) Singly. (N = 54//72)



different beyond that level of significance. The stipulations that the sampling within sets should be random, and that the contributions to the total variance should be additive, were met as far as possible by the experimental design of the investigation, and the conversion of the raw scores into percentages, where necessary. (The notation, say, N = 54//72, means that the actual number of subjects taking part in the experiment was 72, but due to the discarding of the first record of each session only 54 results remained for each of the stimulus conditions.)

6.3. Vertical Parallel Line Interaction as a function of Separation Distance

Figure 6.i. and Table 6.i. show that the simultaneous mean percentage time visible (M.%T.V.) for two vertical parallel lines is inversely related to the separation distance, while the single M.%T.V. is directly related to the separation distance, i.e. as the two lines become closer together, the longer is the time that they are visible simultaneously, with a corresponding decrease in the time that they are visible singly. The graph for simultaneous visibility is almost linear, but with a central inflection, the difference in simultaneous M.%T.V. between the 40 and 10 mm. separation distances being significant at just beyond the 0.01 level, whereas the graph for single visibility shows a gentle linear, but non-significant drop between the separation distances

TABLE 6.i. Mean, Variance and Results of a one way Analysis of Variance on the Percentage Time Visible (%TV) for two Vertical Parallel Lines of varying Separation Distances, visible (a) Simultaneously and (b) Singly. (N = 54//72)

(a) Simultaneous:

Separation Distance mm.	Mean %TV	Difference	Variance
40	66.02	x	345.19
30	69.95		359.26
		9.47	
20	71.61		273.89
10	75.49	x	290.37

F Ratio = 2.57   df = 3, 212   p = 0.05

SE_{dM} = 3.46 $t_{.01} \cdot SE_{dM}$ = 9.05

(b) Single:

Separation Distance mm.	Mean %TV	Difference	Variance
40	12.9	x	83.78
30	11.66		80.26
		6.54	
20	10.70	x	63.91
		4.34	
10	6.36	x x	38.37

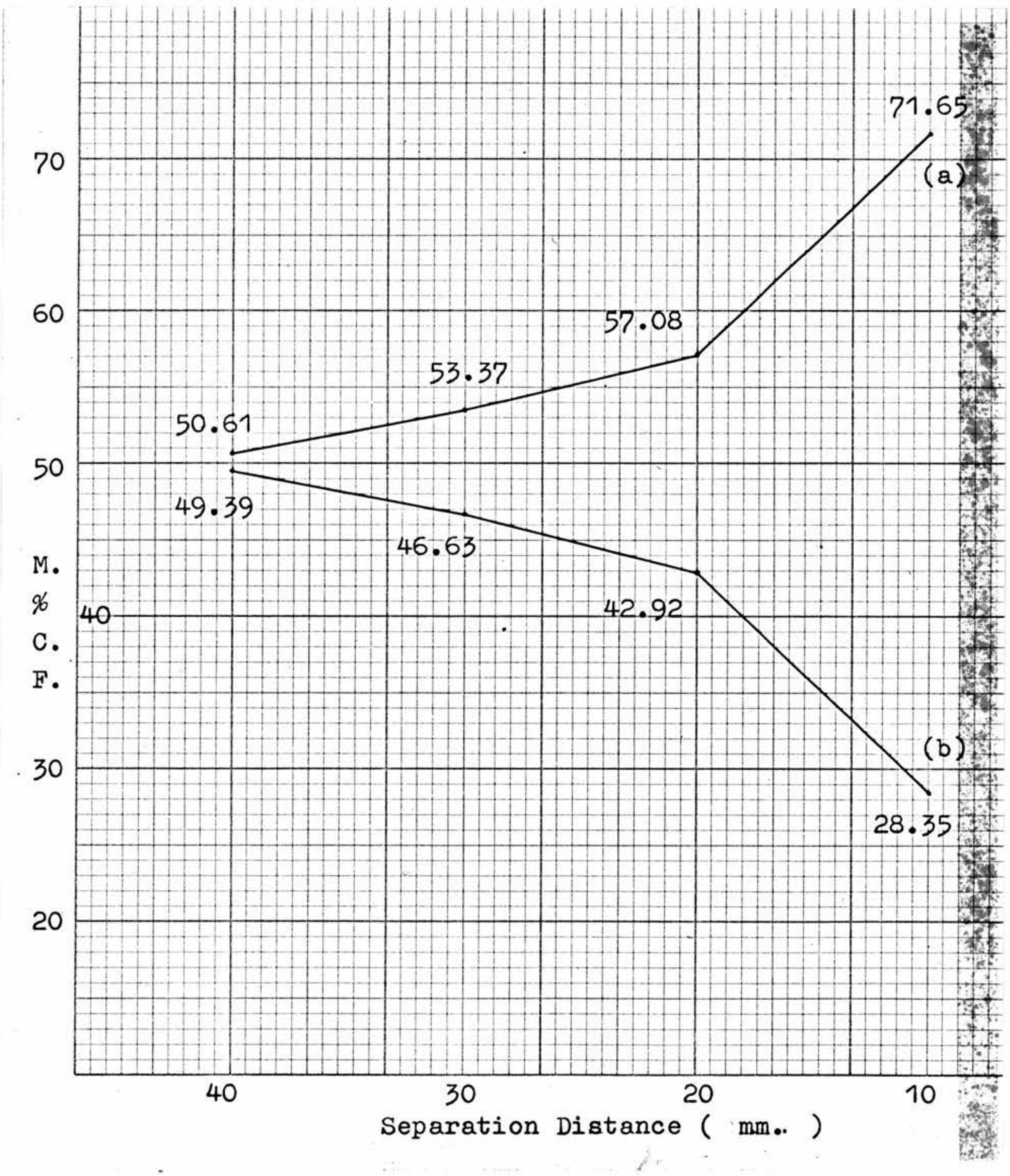
F Ratio = 6.43   df = 3, 212   p $<$ 0.001

SE_{dM} = 1.59   *$t_{.01} \cdot SE_{dM}$ = 4.08

*$t_{.001} \cdot SE_{dM}$ = 5.22

* The corresponding levels of significance are adjusted to $<$ 0.05 and $<$ 0.005 respectively, when the stricter form of determining the significance of the difference between means is used, as here the variances are significantly different.

Figure 6.ii. Graph of the Mean Percentage Change Frequency (M.%C.F.) for two Vertical Parallel Lines of Varying Separation Distances, changing (a) Simultaneously and (b) Singly. (N = 54//72)



40 and 20 mm. There is then a sudden drop between 20 and 10 mm., this being significant at the 0.01 level, while the overall drop between 40 and 10 mm. is significant beyond the 0.001 level.

In Figure 6.ii. the simultaneous mean percentage change frequency (M.%C.F.) for the two vertical parallel lines is inversely related to separation distance, the single M.%C.F. having an identical but reciprocal relationship, both graphs being negatively accelerated, with the values of the M.%C.F. for 40 and 10 mm. being significantly different beyond the 0.001 level (Table 6.ii). In Table 6.iii. are listed the values of the right and left vertical components of the two parallel lines for the remaining dimensions, where it was hypothesised that there would be no significant differences. None are in evidence, as the value of the Standard Error of the difference between the means, multiplied by the appropriate '$t_{.05}$' value (in this case 1.98), would have to exceed the difference between the means for them to be significantly different at this level, and none of the differences are anywhere near approximately twice their respective standard errors.

The only other point worth noting about Table 6.iii. is the high values of the standard deviations relative to the size of their respective means, especially in the case of the mean time of the flash to the first disappearance. This could have been marginally reduced by converting these raw scores to percentages on the basis of the 'total activity' of the AI, i.e. the time from the flash to its last disappearance, while

<u>TABLE 6.ii</u>. Mean, Variance and Results of a one way Analysis of Variance on the Percentage Change Frequency (%CF) for two Vertical Parallel Lines of varying Separation Distances, visible Simultaneously.* (N = 54//72)

Separation Distance mm.	Mean %CF**	Difference		Variance
40	50.61 (49.39	x		657.36
30	53.37 (46.63)	21.4		686.27
20	57.08 (42.92)		x	771.54
			14.57	
10	71.65 (28.35)	x	x	717.38

F Ratio = 6.564   df = 3, 212 $p < 0.001$

SE_{dM} = 5.169 $t_{.01} \cdot SE_{dM}$ = 13.528

$t_{.001} SE_{dM}$ = 17.436

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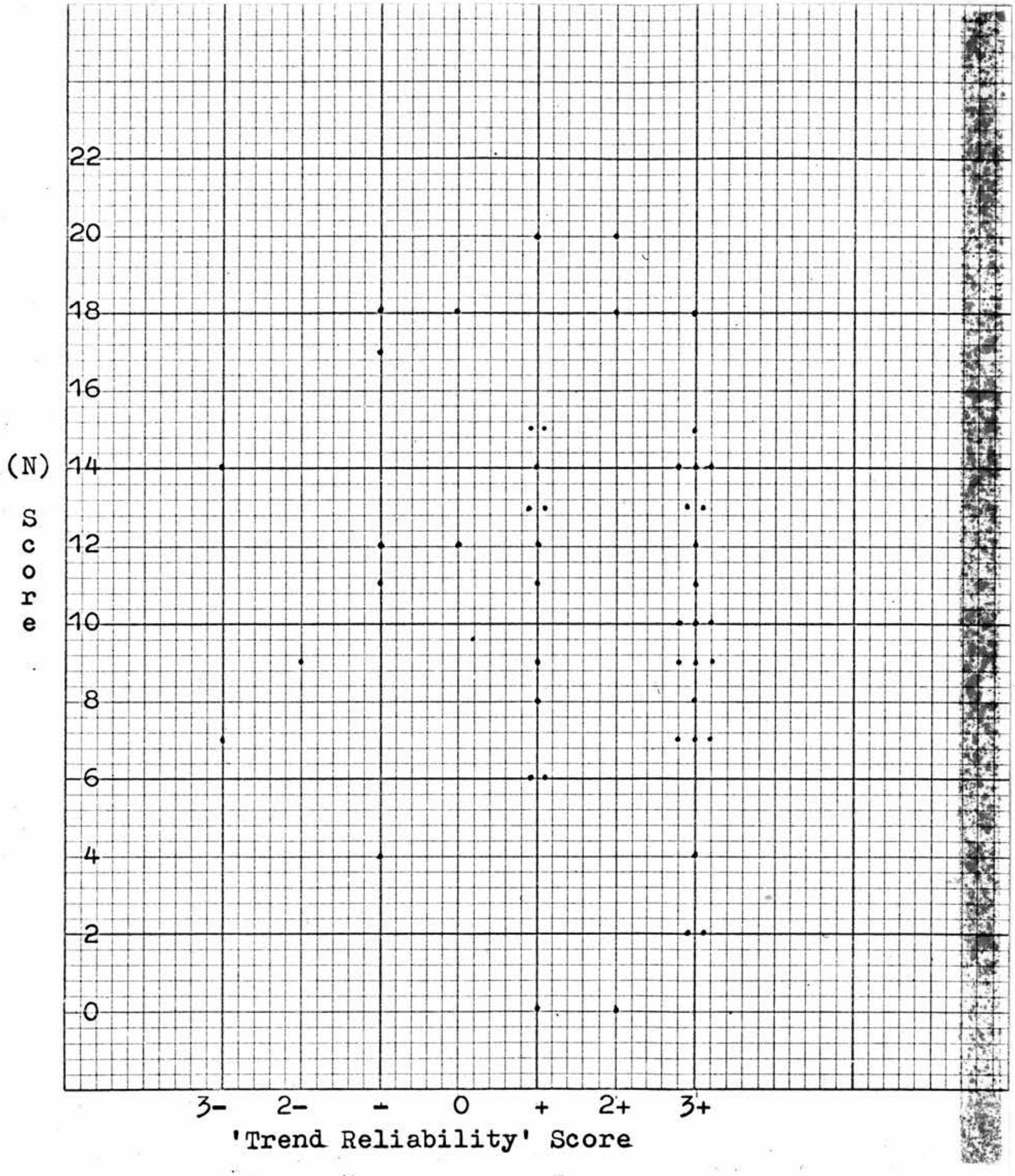
* The data for Single %CF are the same as that for the Simultaneous %CF apart from the means, this being due to the fact that they are mutually dependent.

** Means for the Single %CF are in brackets.

TABLE 6.iii. Mean, Standard Deviation and Standard Error (of the difference between the means) for Right (R) and Left (L) components of the two Vertical Parallel Lines for varying Separation Distances for each of the following dimensions: Percentage Time Visible (%TV), Percentage Change Frequency (%CF), Time from Flash to Last Disappearance (TFLD), and Time from Flash to First Disappearance (TFFD). (N = 54//72)
(* seconds)

	Separation Distance mm.							
	40		30		20		10	
	R	L	R	L	R	L	R	L
M%TV	72.2	71.3	76.7	74.5	78.0	75.9	78.6	78.8
	17.7	20.3	17.6	19.5	15.5	17.0	17.3	16.1
SE_{dM}	3.7		3.6		3.2		3.2	
M%CF	51.4	48.6	49.4	50.6	51.4	48.6	48.3	51.7
	10.3		12.6		11.7		12.9	
SE_{dM}	2.8		3.5		3.2		3.5	
MTFLD*	115.9	115.2	114.6	114.2	116.9	117.3	114.7	114.9
	27.1	26.6	33.2	32.1	28.3	30.1	28.9	29.2
SE_{dM}	5.2		6.3		5.7		5.6	
MTFFD*	37.0	39.0	40.5	41.6	37.1	44.6	42.4	41.6
	31.5	29.4	31.0	33.7	33.7	39.9	36.4	36.5
SE_{dM}	5.9		6.3		7.2		7.1	

<u>Figure 6.iii</u>. 'Trend reliability' score plotted against E.P.I. (N) score for the first 48 subjects.



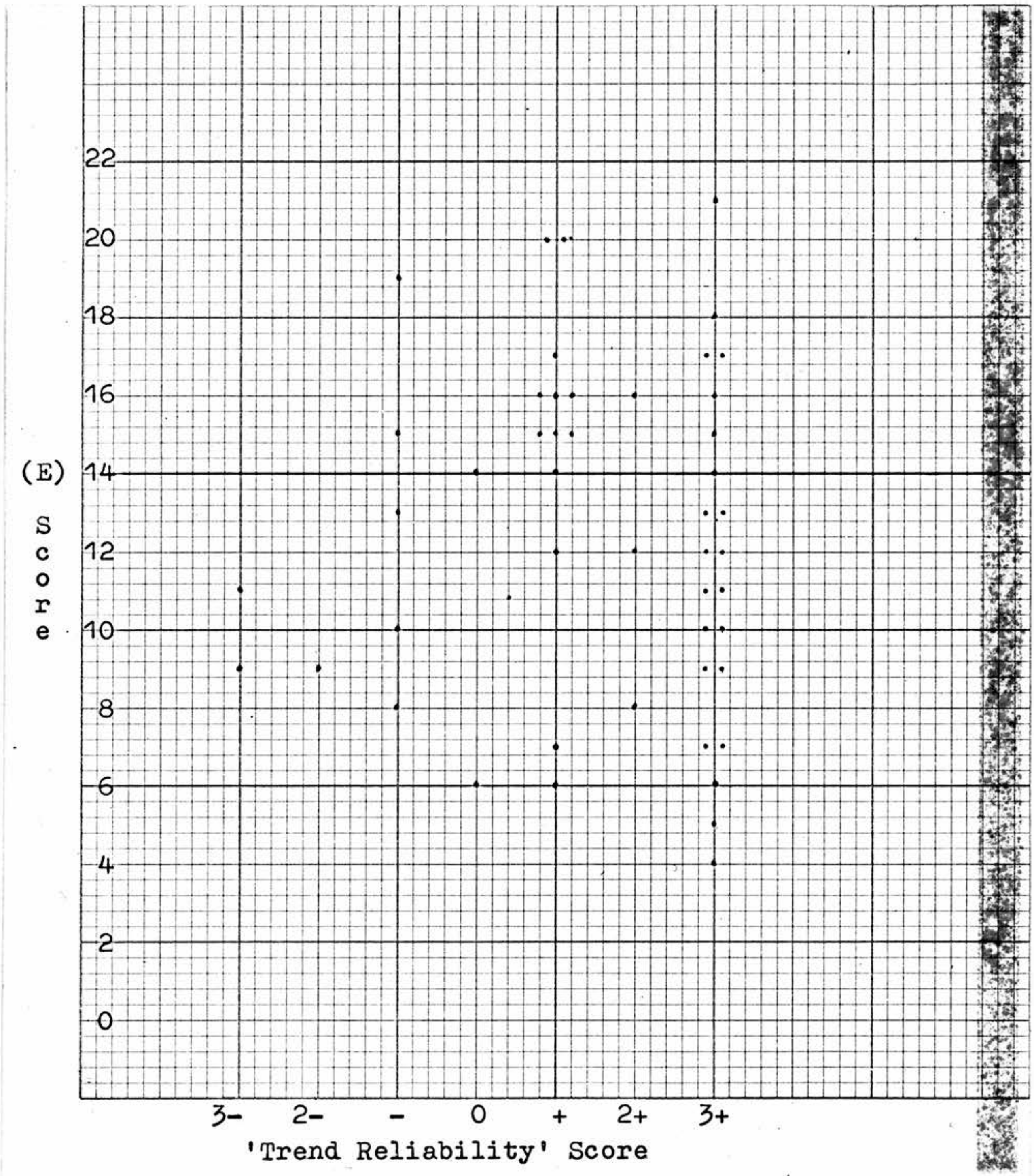
conversion to standard scores would, perhaps, have been a more appropriate procedure, but it was unlikely that anything of additional value would have been obtained.

The mean percentage simultaneous time visible for the vertical parallel lines was also calculated on the basis of ORDER OF PRESENTATION, to check that there was no transition on this continuum. The experimental design was such that it would have 'spread' any such effect evenly over the four stimulus conditions; however, the means for positions 2, 3 and 4 were 70.51, 71.27 and 70.53 respectively, the standard error of a difference between means being 3.04, thus showing no notable change.

As an estimate of a subject's 'trend reliability' in this experiment, the direction of change in (1) percentage single time visible, (2) percentage simultaneous time visible and (3) single change frequency, as the stimulus bars become closer together, was compared to that which was predicted. If the direction of change was in the predicted direction then that measure was accorded a (+); if in the opposite direction a (-); if no change a (o). A 'reliable' subject performing as predicted would therefore have a total 'score' of 3+ while a 'reliable' subject performing opposite to that predicted would have a total score of 3-. 'Unreliable' subjects, i.e. those 'conforming' on two dimensions but not on the third or vice versa, would have a score of + or - respectively, etc.

Each subject's total score was plotted against his N score (Figure 6.iii.) and against his E score (Figure 6.iv.).

Figure 6.iv. 'Trend reliability' score plotted against E.P.I. (E) score for the first 48 subjects.



If for E, one considers only those subjects with scores of 3+ and +, i.e. 'reliable' and 'unreliable' subjects with most of their scores in the predicted direction, then the optimum point at which to draw a cut off line (to maximise the number of 'reliable' and minimise the number of 'unreliable' subjects) is at E = 14 as then one has 9 'unreliable' and 6 'reliable' subjects above this value and 3 'unreliable' and 15 'reliable' below it: a (Yates Corrected) Chi-square on these frequencies gives a $p < 0.05$, thus confirming a significant (positive) relationship between E scores under 14 with 'trend reliability'. No significant relationship was found to exist for the N scores.

Graphs of the mean number of perspective changes/minute plotted against the extent of the change in (1) percentage single time visible, (2) percentage simultaneous time visible and (3) single change frequency, as the stimulus bars become closer together, are shown in the Appendices, sub-sections 10.4.1. - 10.4.3. respectively, (+) changes being in the hypothesised direction. There is a slight tendency for the extent of the change in a dimension to be greater for subjects with a higher measure of level of arousal.

TABLE 6.iv. Results of a one way Analysis if Variance on the Percentage Time Visible for two Vertical Parallel Lines of 10 mm. separation, varying in Foveal Placement, visible (a) Simultaneously and (b) Singly. (N = 48//72)

(a)

Foveal Placement	Mean Sim. % T.V.	Variance
Parallel Lines Equidistant	78.40	280.63
" " 10 mm. to Right	72.64	385.21
" " 10 mm. to Left	78.44	205.79

SE_{dM} = 3.156

(b)

Foveal Placement	Mean Single % T.V.	Variance
Parallel Lines Equidistant	6.09	27.35
" " 10 mm. to Right	12.11	143.63
" " 10 mm. to Left	7.69	48.38

F Ratio = 6.255 df = 2,141 $p < 0.005$

SE_{dM} = 1.764 $^{*}t_{.02}\cdot SE$ = 4.103

$^{*}t_{.001}\cdot SE$ = 5.949

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* The corresponding levels of significance are adjusted to >0.05 (insignificant) and <0.05 (still significant) respectively, when the stricter form of determining the significance of the difference between the means is used, as here the variances are very significantly different.

6.4. Vertical Parallel Line Interaction as a function of Foveal Placement

Table 6.iv. shows that for two vertical parallel lines, varying in foveal placement, there is a tendency for the lines to be seen simultaneously for a longer time, when they are equidistant or to the left of the fixation spot, than when they are to the right of it, the inverse relationship being obtained for single mean time visible. For the simultaneous 'activity' the differences are not significant, whereas for the single 'activity' they are. Similar, but non-significant differences were found for mean percentage change frequency (Table 6.v.), thus indicating a tendency for the AI of two vertical parallel lines, when seen to the right of the fixation spot, to be less 'stable' than when seen either centrally or to the left.

Table 6.vi. shows the difference between the right and left components of two vertical parallel lines, when they are either to the right or to the left of the fixation spot, the outer line being visible longer than the inner one. The difference was significant only for lines appearing to the right of the fixation spot ($p < 0.05$), there being, of course, no difference when the lines were equidistant. Similar differences were found when the percentage change frequencies were analysed (Table 6.vii.), the outer line having a significantly lower percentage change frequency than the inner one in both instances ($p < 0.005$). The results of an analysis of

Table 6.v. Mean, Standard Deviation and Standard Error for the Percentage Change Frequencies (%CF) for two Vertical Parallel Lines of 10 mm. separation, varying in Foveal Placement.*

Foveal Placement	Mean % C.F.		
	Simultaneous	Single	σ
Parallel Lines Equidistant	65.8	34.2	27.6
" " 10 mm. to Right	56.3	43.7	32.1
" " 10 mm. to Left	63.3	36.7	28.4

$SE_{dM} = 6.07$

Table 6.vi. Results of a one way Analysis of Variance on the Percentage Time Visible for the Left and Right Parallel Lines of 10 mm. separation, varying in Foveal Placement.*

Foveal Placement	Mean % Time Visible	
	Left	Right
(o) Par. Lines Equidistant	81.56	81.33
(a) " " 10 mm. to Right	74.99	82.40
(b) " " 10 mm. to Left	83.91	80.65

(o) $SE_{dM} = 3.39$	σ	16.7	16.2
(a) $SE_{dM} = 3.71$	σ	18.9	17.0
F Ratio = 3.98 df = 1, 94		$p < 0.05$	
(b) $SE_{dM} = 2.82$	σ	13.8	13.6

* N = 48//72

Table 6.vii. Results of a one way Analysis of Variance on the Percentage Change Frequencies for Left and Right Parallel Lines of 10 mm. separation, varying in Foveal Placement.*

Foveal Placement	Mean % Change Frequency	
	Left	Right
(o) Parallel Lines Equidistant	48.71	51.29
(a) " " 10 mm. to Right	55.23	44.77
(b) " " 10 mm. to Left	44.49	55.51

(o) Variance within either column = 100.37

SE_{dM} = 2.92

(a) Variance within either column = 138.66

F Ratio = 9.254 df = 1,47 $p < 0.005$

SE_{dM} = 3.44

(b) Variance within either column = 120.44

F Ratio = 11.841 df = 1,47 $p < 0.005$

SE_{dM} = 3.20

* N = 48//72

Table 6.viii. Mean, Standard Deviation and Standard Error (of the difference between the means) for the Right (R) and Left (L) components of the two Vertical Parallel Lines for varying Foveal Placement, for Time from the Flash to the Last Disappearance (TFLD) and the Time from the Flash to the First Disappearance (TFFD). (N = 48//72)

	Foveal Placement (relative to the fix. spot)					
	Lines Equidistant		Lines to Right		Lines to Left	
	R	L	R	L	R	L
Mean TFLD*	112.8	113.4	112.6	107.9	115.8	116.1
σ	24.0	23.4	25.6	28.9	31.4	30.5
SE_{dM}	4.9		5.6		6.4	
Mean TFFD*	46.2	53.2	44.9	37.2	32.4	43.4
σ	37.9	40.7	40.7	34.9	30.7	39.5
SE_{dM}	8.1		9.5		7.3	

* Measured in seconds

of both of these dimensions therefore show evidence of greater 'instability' of the inner of the two lines.

There was a very distinct tendency for the off centre after-images to move in the direction in which the bars were off centre. This would have been quite important if the outer line had been found to be more 'unstable' than the inner one, as the outer line would be at the 'apparent periphery' of the subject's field of view, when the AI moved to the extreme lateral position.

To check if there was any possibility that the 'instability' of the inner line was due to it falling on or close to a previously stimulated area of the retina, due to eye movement during fixation, the percentage change frequencies for the first flash of each run were investigated. These values were very similar to those found in the remaining records for each component of the AI, there being virtually no difference between the %CFs when the lines were equidistant (52.0 and 48.0), but when the lines were off centre the inner lines %CF was much greater than that of the outer: 56.4 and 43.6 when they were to the right of the fixation spot, and 40.2 and 59.8 when to the left. Thus the instability of the inner of two off centre vertical parallel lines was not due to this possibility.

The values of the mean times from the flash to the first and last disappearances of the AI are given in Table 6.viii., there being no significant differences. The large variances for the mean times from the flash to the first disappearance is due to those subjects who did not have a disappearance and a reappearance of the AI before the final disappearance, their TFFD therefore being equal to their TFLD.

The results of pilot experiments conducted at the end of this experiment are to be found in sections 10.5. - 10.7. of the Appendices, the three experiments being:

1) Binocular Vision: vertical parallel line study;

2) Non-dominant Eye: vertical parallel line study;

3) Horizontal parallel line study (dominant eye).

Relative to the dominant eye condition it was found that there were no significant differences between conditions 1) and 2), or between 3) and its vertical counterpart.

TABLE 6.ix. Mean, Standard Deviation and Standard Error for a vertical line plus one varying in orientation and vice versa, for the following dimensions: Simultaneous Percentage Time Visible (S%TV), Single Percentage Time Visible (Si%TV), Simultaneous Percentage Change Frequency (S%CF). (N = 72//96)

<table>
<tr><th></th><th colspan="4">Target Configuration</th></tr>
<tr><th></th><th>| |</th><th>| /</th><th>| —</th><th>| \</th></tr>
<tr><td>Mean S%TV</td><td>70.5</td><td>71.3</td><td>71.3</td><td>66.6</td></tr>
<tr><td></td><td>18.0</td><td>17.5</td><td>17.9</td><td>19.1</td></tr>
<tr><td>$SE_{dM} = 3.04$</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mean Si%TV</td><td>13.8</td><td>15.8</td><td>14.8</td><td>15.3</td></tr>
<tr><td></td><td>10.2</td><td>12.9</td><td>11.2</td><td>11.5</td></tr>
<tr><td>$SE_{dM} = 1.93$</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mean S%CF*</td><td>47.6</td><td>40.9</td><td>44.3</td><td>46.0</td></tr>
<tr><td></td><td>(52.4)</td><td>(59.1)</td><td>(55.7)</td><td>(54.0)</td></tr>
<tr><td></td><td>27.9</td><td>28.5</td><td>30.7</td><td>27.0</td></tr>
<tr><td>$SE_{dM} = 4.79$</td><td></td><td></td><td></td><td></td></tr>
</table>

* The Means for the Single Percentage Time Visible are in brackets, the Standard Deviations and Standard Error being the same, as the two dimensions are mutually dependent.

6.5. Line Interaction as a function of Orientation

In this investigation, the results for a line of varying orientation to the right were added to those for it varying to the left, for each of the four orientations, this also being done for the accompanying vertical line. No significant differences were found between the means for the four target configurations, simultaneous or single percentage time visible and time from the flash to the first or last disappearance, there being no evidence of any dissimilarity between a vertical plus either another vertical or a horizontal on the one hand, and a vertical plus either of the two forty-five degree diagonals (Table 6.ix.).

When the means for the percentage time visible, percentage change frequency and the time from the flash to the first or last disappearance, for the corresponding components of the target configurations, were examined (Table 6.x.), no significant differences of the kind predicted were in evidence, there being even a slight tendency for the variable line to be more stable than the vertical. Ironically, there was a significant difference ($p < 0.05$) between the percentage change frequencies for the components of the two vertical lines, and a tendency in the same direction for the means of the other components. The reason for the values of the standard deviations being high, relative to the means, for the time from the flash to the first disappearance, is the same as mentioned before.

TABLE 6.x. Mean (M), Standard Deviation and Standard Error for corresponding components of a vertical line plus one varying in orientation and vice versa, for the following dimensions: Percentage Time Visible (%TV), Percentage Change Frequency (%CF), Time from Flash to Last Disappearance (TFLD), and Time from Flash to First Disappearance (TFFD). (N = 72//96)

	Target Configuration							
	$\vert$	$\vert$	$\vert$	/	$\vert$	—	$\vert$	\
M%TV	76.1	78.7	77.3	80.9	78.0	79.3	72.9	75.6
σ	17.0	16.3	16.0	14.9	17.1	15.2	17.9	16.7
SE_{dM}	2.8		2.6		2.7		2.9	
M%CF	52.7*	47.3	51.5	48.5	50.4	49.6	50.2	49.8
σ	10.7		13.6		13.1		9.6	
SE_{dM}	2.53		3.2		3.1		2.3	
MTFLD**	114.7	115.8	108.4	113.4	109.7	109.3	113.6	115.9
σ	31.8	32.1	33.8	35.5	34.3	34.4	31.0	27.1
SE_{dM}	5.4		5.8		5.8		4.9	
MTFFD**	34.8	41.9	41.9	47.1	47.3	48.4	37.1	39.9
σ	23.1	32.2	27.9	37.6	36.6	34.6	31.2	33.9
SE_{dM}	4.7		5.6		6.0		5.5	

* Significantly different p = 0.05.

** Measured in seconds.

TABLE 6.xi. Mean, Standard Deviation and Standard Error of the percentage time visible, for the corresponding components of a vertical line plus one of varying orientation in terms of order of presentation. (N = 96)

	Order of Presentation					
	2		3		4	
	Vert.	Var.	Vert.	Var.	Vert.	Var.
Mean %TV	75.16	75.27	77.06	79.78	76.02*	80.78
σ	17.60	16.82	16.33	15.27	17.36	15.05
SE_{dM}**	2.50		2.29		2.36	

* The difference between these two means is significant at just beyond the 0.05 level.

** The SE_{dM} for the variable lines 2 and 4 is 2.32, the difference being significant at just beyond the 0.02 level.

The mean percentage time visible for the corresponding components of a vertical line plus one of varying orientation was calculated on the basis of ORDER OF PRESENTATION (Table 6.xi.). It was found that there were no significant differences between the vertical lines through the series, but for the variable lines there was a marked increase between the second and third presentations, significant differences were obtained between the vertical and the variable line in presentation four ($p < 0.05$), the variable mean being the larger, and between the variable lines in presentations two and four ($p < 0.02$).

TABLE 6.xii. Mean, Standard Deviation and Standard Error for single lines, varying in orientation, for the following dimensions: Percentage Time Visible (%TV), Change Frequency (CF), Time from the Flash to the Last Disappearance (TFLD) and Time from the Flash to the First Disappearance (TFFD). (N = 36//48)

	Orientation			
	Vertical	Diagonal	Horizontal	Diagonal
Mean %TV	77.4	75.0	77.8	76.3
σ	14.8	16.8	17.1	15.2
$SE_{dM} = 3.8$				
Mean CF	9.9	8.5	8.0	8.7
σ	7.6	5.8	4.7	6.2
$SE_{dM} = 1.5$				
Mean TFLD	98.5	89.9	92.2	88.9
σ	32.7	34.7	30.0	33.5
$SE_{dM} = 7.8$				
Mean TFFD	33.9	34.0	39.0	34.5
σ	23.4	20.5	23.4	22.0
$SE_{dM} = 5.4$				

6.6. Line Stability as a function of Orientation

In this study, the results for the line appearing to the right of the fixation point were added to those for it appearing to the left, for each of the four orientations. As expected, there were no significant differences between the various orientations for any of the dimensions (Table 6.xii.). The standard deviations for the change frequencies are large relative to the means, this being due to the values being raw scores, there being nothing, in this instance, which could be used to convert them to percentages. The standard error of the difference between means for change frequency is not particularly reliable, as the variances for each of the means are markedly different. Again, the standard deviations are large, relative to the means, for both the time from the flash to (a) the last disappearance and (b) the first disappearance, especially in the latter, due to those subjects whose TFFD was equal to their TFLD.

6.7. Resume

Six usable dimensions were extracted from the pen records and the timer readings, two of which were converted to percentages. The group data was processed using a modified (one way analysis of variance) computer program, care being taken to meet the inherent assumptions and to make suitable adjustments to the analysis where necessary.

In studying vertical parallel line interaction as a function of separation distance, it was found, as predicted, that, as the separation distance decreased, both the simultaneous percentage time visible and change frequencies increased significantly, and vice versa for the single activity, there being, as expected, no significant differences in the analysis of the remaining dimensions, or in terms of order of presentation. Subjects with E scores under 14 were found to have significantly more 'trend reliability' than those with E scores over 14, but no significant relationships were found with degree of neuroticism or 'level of arousal'.

In studying vertical parallel line interaction as a function of foveal placement, it was found that there was a tendency for them to be less stable when seen to the right of the fixation spot, than when seen either centrally or to the left. When the lines were off centre, either to the right or left, the inner of the two lines was significantly less stable than the outer for the two main dimensions.

In studying line interaction as a function of orientation, no significant differences were found between the stimulus conditions or the corresponding components, for any of the dimensions, apart from one between the means for percentage change frequency for two vertical lines - a definite anomaly. No significant differences were obtained between the vertical lines in terms of presentation order, but a significant increase was found between the variable lines through the series.

In studying line stability as a function of orientation, as expected, no significant differences were found between the orientations for any of the relevant dimensions.

7. DISCUSSION

7. DISCUSSION

In this chapter, coverage will first be given to those aspects which are specific to the actual experiments performed in this study, mention being made of possible explanations for the findings. An appraisal of certain physiological considerations related to the study as a whole will then be given in order to put the experimental findings in context.

7.1. Specific Considerations Related to the Individual Topics

Before reflecting on the actual experimental findings, it is worth making passing reference to the differences in the disappearance/reappearance frequencies and times that occur under two commonly used procedures for reporting stabilized retinal image phenomena, i.e. (a) a continuous taped verbal report and (b) reporting only when the whole figure disappears (off) or when all or part of it reappears (on). It has been found by Dicara and Barmack (1965) that the use of a detailed reporting procedure reduces the likelihood of total image disappearance, and increases the total time that the image is visible. Mention is made of four possible hypotheses concerning the increased stability of a stabilized retinal image, when a running commentary, reporting procedure is utilized, i.e. that it (a) raises the level of activation; (b) produces more headmovement, thus causing destabilization; (c) causes more eye searching activity; (d) produces a closer focussing of attention on detail, thus enhancing the persistence of the object of attention. As the key pressing reporting procedure used in the present study is similar to their (on-off) procedure, it seems very likely that a fuller, continuous verbal report would have increased the visibility times and decreased the disappearance/reappearance frequencies, but this would have reduced the study to a qualitative level if deployed alone. It is also possible that if a full reporting procedure had been used in conjunction with key pressing, the latter might have suffered in precision of execution. However, as the same reporting procedure was used throughout this study, the only consequence of Dicara and Barmack's finding to this investigation is that it must be borne in mind when comparing the results of the present study with others using continuous verbal reporting procedures.

7.1.1. Vertical parallel line interaction as a function of separation distance

The increases in simultaneous visibility and change frequency found when the two vertical parallel line after-image's separation distance decreased, could be explained on a number of grounds. On a retinal basis, as the area stimulated in this study was the rod-free area of the fovea, increases in visibility as the separation distance decreased (which is related to simultaneous visibility and change frequency) could be due to the increased number of foveal cones stimulated, cone density per unit area increasing by a factor of 3 over the range stimulated in this study (Polyak, 1957), which was from just under 9' to just over 34' of arc from the centre of the fovea. This hypothesis, being based on accepted retinal anatomical findings, does recommend itself more than the diffuse hypothetical cortical field effects postulated by Cohen (1961) and Hebb (1963). That this hypothesis has some validity is shown by a similar study utilizing single bars at identical distances from the centre of the fovea (see Appendix 10.8.). Here the finding was that as the bar became closer to the centre of the fovea, its percentage time visible increased significantly. This 'retinal density' theory could also explain Cohen's (1961) results using a stabilized image in one eye and an unstabilized image in the other, as the unstabilized line, when it came closer to the stabilized line (in terms of retinal angle), would be stimulating a greater number of foveal cones.

However, one can rule out this hypothesis as an explanation of the obtained findings on parallel line interaction on the grounds that if this factor was operating here, then the total mean % T.V. (single + simultaneous) for the different separation distances should have increased significantly as the separation distance decreased. In reality there is little change, the means being 78.92, 81.61, 82.31 and 81.85 respectively (from Table 6.i.). A more interesting and viable hypothesis is that in the human cortex there are the simple cells that have been found by Hubel and Wiesel (1962) in the cat (mention is also made of similar findings in the monkey*). These simple cells are arranged in columns perpendicular to the surface of the striate cortex, each column containing cells giving a maximum response to linear retinal stimuli of a certain orientation lying within a particular area of the visual field. Depending on the size of the bars used, more than one simple cell (having identical field orientations adjoining each other on a common axis) might be required to correspond cortically to each of the bars. However, simple cells, corresponding to linear stimuli of the same orientation in a particular area of the visual field, drive complex (cortical) cells, which respond to movement of an identically oriented linear stimulus in a particular direction. If these simple and complex cells, having receptive fields as outlined above, exist in the human cortex, then, as the two stabilized parallel lines become closer together in terms of retinal angle, the greater is the likelihood of their corresponding simple cells being those which drive adjacent complex cells and finally the same complex cell. Thus the neural connections from the two bars become progressively more closely linked, ending up at a certain separation distance being connected to the same complex cell; one might therefore anticipate progressively more simultaneous behaviour as the

* These findings have been further elaborated by Hubel and Wiesel (1968), and show that the response properties of most cells in the macaque and spider monkey's striate cortex are very similar to those found in the cat, but on average "the receptive fields are smaller and there is a greater sensitivity to changes in stimulus orientation", p. 215.

bars become closer together, and perhaps a marked increase when both potentially drive the same complex cell. Such a sudden change is seen in Figure 6.ii. where simultaneous mean percentage change frequency increases linearly with decreases in separation distance from 40 mm. to 20 mm. (i.e. 68.7' - 34.3' of arc), there being a very marked increase ($p < 0.01$) when the separation distance further decreases to 10 mm. (i.e. 17.2' of arc). This could be taken to indicate that the 'field size' of a complex cell in the central rod-free area of the fovea is somewhere under 34' but over 17' of arc: a more feasible explanation is that the two bars in this instance lie within the narrow regions on each side of the vertical meridian, which has direct callosal interconnections (see section 7.1.2.), thus greatly facilitating simultaneous activity.

The predicted finding that subjects with E scores above a certain value (in this instance 14) tend to have significantly less 'trend reliability' than subjects with E scores under this value, indicates that the flippancy associated with marked extraversion can have a detrimental effect on the reliability of reports on bar after-image visibility. Subjects with high N scores, and who are therefore somewhat unstable, also exhibit a tendency to be slightly more unreliable, but not to a significant extent. The findings on level of arousal, as measured using rate of necker cube reversal, though showing a very slight tendency in the predicted direction, are of little significance as this measure is relatively crude in comparison with more sophisticated techniques using basal skin conductance (cf. Duffy, 1962). Nevertheless it is worth pointing out that Sherwood (1965) obtained a significant relationship between level of arousal (using necker cube reversals) and performance as measured by short term retention in paired associate learning, thus indicating that rate of perspective reversal is of some consequence.

7.1.2. Vertical parallel line interaction as a function of foveal placement

The tendency for the parallel line configuration to be somewhat less 'stable', when falling solely on the right hand visual field (as compared with it falling on the left, or on both together), is somewhat difficult to explain. The findings on tachistoscopic recognition of horizontal rows of geometrical forms as a function of retinal locus (Bryden, 1960) show that there is no difference in ease of recognition, when they are presented successively in either the right or the left visual field. Nevertheless, when they are presented in both fields simultaneously, they are recognised more accurately in the left visual field than in the right.

The finding that the inner bar was significantly less stable than the outer bar, when the configuration fell on solely the left or right visual field, is perhaps best explained on the basis of a cortical hypothesis, it being unlikely that the radial structure of the foveal ganglion fibres has any connection with this finding (Whitteridge, 1967). Myers (1962) has shown that there is very clear anatomical evidence that it is only in areas 18, in the occipital cortex of the monkey, that there are connections between corresponding points of the cerebral hemispheres via the corpus callosum, and that there are none in area 17 (the striate cortex) or area 19. Now Daniel and Whitteridge (1961) have found that the boundary of area 17 in the monkey is almost completely formed by the representation of the vertical meridian in its visual field, and it has been shown by Choudhury, Whitteridge and Wilson (1965) that, in the cat and baboon, these connections between corresponding points in the opposite hemisphere in area 18 are of functional significance: for the cat simple field cells (as described by Hubel and Wiesel, 1959) were found to be interconnected by trans-callosal fibres. The hypothesis put forward by Choudbury _et al_. was that "cells of the visual cortex whose receptive fields are closely adjacent to the vertical meridian and are similarly oriented, are linked to each other via areas 18 and the corpus callosum. Presumably this is a mechanism by which lines in one visual field are linked to corresponding lines in the other field" (page 218).

Whitteridge (1965) believes that if a similar mechanism exists in man, then its purpose is to relate the two halves of the visual field (which are projected to different hemispheres) thus functionally locking them together. On the basis of the above findings, Whitteridge (1967)* is of the opinion that the relative 'instability' of the inner of a pair of offset bars found in the present study could be explained by the inner bar falling within the narrow band (which lies on either of the meridian) having functional interconnections between corresponding simple cells in areas 18 of the two hemispheres. Under normal fixation conditions, a linear stimulus falling on a retinal region, slightly to the right of the vertical

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* Personal communication.

meridian (due to physiological nystagmus), would stimulate the corresponding simple cell(s) lying just to the left of the meridian. This stimulation of the corresponding linear receptive field would be lost when a stabilized line was viewed in such a position, thus weakening its visibility, as under normal conditions 'confirmatory' impulses would be given to the corresponding simple cell(s) by stimulation of its receptive field.

A relatively straightforward experiment was performed to ascertain whether this central hypothesis was more tenable than, say, some connection between the radial distribution of the foveal ganglion fibres and the obtained findings. An identical experiment to the one already performed was implemented (see Appendix 10.9.) with the bars lying horizontally. The findings of this study seemed to indicate that there was little evidence for a difference in the stability of the bars when horizontal as compared to the vertical condition, thus discounting the 'radial' hypothesis in this connection.

7.1.3. Line interaction as a function of orientation

That this study revealed no evidence that two stabilized vertical parallel lines behave any differently from two identically positioned lines, one vertical, the other of variable orientation, needed some further investigation. Since it was the results of Tees' (1961) investigation (using two parallel vertical lines with an interposed 45° diagonal) which initiated the present study, it was decided to replicate (as far as possible) this investigation. Detailed results of this further study are shown in Appendix 10.4., and are in keeping with those of Tees, in that the diagonal was visible for a significantly shorter time than either of the two vertical parallel lines: the diagonal was also less 'stable' in that it had a significantly increased mean percentage change frequency in comparison with the outer verticals.

A possible explanation for there being no significant differences in the predicted direction for the main study, might be due to the non-vertical bar being 'novel' relative to the vertical bar, as this particular study had been preceded by one concerned with vertical parallel line interaction as a function of separation distance, thus increasing the subject's interest in the non-vertical bar, and leading to its stability being raised to that of the vertical. It is worth pointing out that, had differences been found in the predicted directions (section 4.1.3.), then one could haveevoked a 'simple/complex cell' hypothesis similar to that mentioned in section 7.1.1., there being less simultaneous activity in those stimulus configurations where the variable bar was diagonal, as the corresponding simple cells would be projecting to different complex cells. The instance where the variable bar is horizontal would be covered by the 'hyper-complex cell' hypothesis mentioned in section 4.1.3., which predicted that there would be no difference between the behaviour of two parallel lines, and two identically positioned lines, one at right angles to the other. However, if these two 'cell' hypotheses had been operative along with the 'novel' hypothesis in the present study, then the visibility of the horizontal bar would have been raised above that of the rest, and this was not found to be the case.

The finding, that, in terms of order of presentation, there was a significant increase in mean percentage time visible through the series for the variable lines as a group, while there was no such increase for the vertical lines, is rather difficult to explain. Had the variable bars appeared 'novel' relative to the vertical one, then one would have expected a marked difference between them in position one or two, but diminishing in magnitude in positions three and four. The fact that through the series, the variable bar (apart from its centre) is falling on a virtually unstimulated part of the retina, while the vertical bar is continually falling on approximately the same area, might be thought to be contributing to the phenomena, but if some form of 'satiation' were occurring (alone), then the visibility of the vertical bar should have fallen off through the series, but in fact it remained virtually constant.

However, if through the series, the above 'satiation' was occurring along with a negatively accelerated increase in level of awareness (cf. Hebb, 1955) giving rise to increased visibility, then they could conceivably cancel each other out for the vertical bar, but the variable bar would only be subject to the latter, thus resulting in the increase in visibility found through the series in Table 6.xi.

7.1.4. Line stability as a function of orientation

Here the results are in keeping with the predictions based on the finding by Hubel and Wiesel (1962) that there was no predominant orientation to be found among the simple cortical cells of the cat. Similar results to that of the present study were found independently by Evans (1966), in that for after-image lines (of varying length), there were found to be no significant differences in unitary and fragmentary disappearances for four different orientations ("12", "1", "2" and "3" o'clock). However, it is worth noting that Craig and Lichtenstein (1953) found that when subjects fixated the centre of a large, white visual field from which a thin, black line radiated outwards, then this line subjectively disappeared and reappeared at irregular intervals during the fixation period, the diagonal orientations being less 'stable' than either the vertical or horizontal orientations.* More marked physiological nystagmus along both of the diagonal axes, than along the horizontal and vertical axes, would seem to be the most likely of the hypotheses offered by Craig and Lichtenstein, as subjects do have 'favoured' axes for flicks and drifts during fixation, these, however, being somewhat variable between subjects (Fiorentini and Ercoles, 1966).

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* Some further support for these findings could be implied from Andrews (1967), who has shown that central foveal acuity performance is better for vertical and horizontal flashed lines (subtending either 5.52' or 7.36' arc) than for lines of intermediate orientation.

7.2. Physiological Considerations Related to the Study as a Whole

The following sections will deal with the inhibition of the after-images by eyemovement, showing that eyemovements above a certain magnitude result in their disappearance, this being of some consequence in the present study; the relationship of the after-images to stabilized retinal images, indicating that in many respects their subjective behaviour is very similar, thus relating the present findings to those using conventional techniques; the localization of the phenomena associated with flash stabilized after-images, observing that they have both retinal and cortical origins.

7.2.1. Inhibition of the after-images by eyemovement

It should be pointed out that there was a considerable degree of variation between subjects in their ability to keep the after-image of the flashed target in a 'straight ahead' position, as some found that it tended to drift. This apparent movement was the result of the eye moving relative to the eyesocket, due to the lack of any reference point, eyemovement in the dark usually being in excess of that under 'normal' conditions (Ditchburn and Ginsborg, 1952; Fiorentini and Ercoles, 1966). The provision of a reference spot of light would have been of doubtful value, as this would have moved, due to autokinesis, and would have probably resulted in a variety of movement either separately or together (Piggins, 1965). However, some subjects experienced no difficulty in maintaining the after-image within a very small 'field of movement', and only a few had considerable trouble with excessive after-image movement. It was found that there was a more marked tendency for the after-image to disappear when it reached the 'apparent periphery of the field of vision'; when the rate of drift was relatively fast; or when the subject made a large 'corrective' flick. This inhibition of the after-image is in keeping with the findings of Fiorentini and Mazzantini (1965), who found that voluntary flicks in excess of 1^{o} of arc always resulted in the disappearance of an after-image, and that tracking at a rate of 10^{o}/second resulted in a high probability of disappearance (approximately 0.9). They also found that if a small amplitude saccade (30' of arc) resulted in the disappearance of an after-image, then the time taken for its "regeneration" was the same as for larger movements, the actual average time course being a function of the individual observers, but was usually under ten seconds.

A partial explanation of the disappearance of an after-image following an eyemovement can be derived from retinal sensitivity to stimuli under more 'normal' conditions. Volkman (1962), using 20 μ sec flash patterns, has shown that vision is not "blanked out" during a voluntary saccade, but that the increment threshold is increased by a factor of 3 (actually 0.5 log unit higher), the sensitivity not being fully recovered by the end of the movement. He interprets his results as indicating that central inhibition alone is unlikely to account for the phenomenal "continued clear vision", and that the fact that we do not perceive impinging stimuli during saccades must be largely attributed to "retinal smear, which serves to decrease the photo-chemical effect of stimulation" (page 578). However, Latour (1962) found that the detection probability for a 50 μ sec flash having an intensity of about 3 log units above threshold, started to decrease about 40 milli seconds before the start of a voluntary saccade, fell to almost zero at the onset of movement, but returned to unity by the end of the movement. It would seem, therefore, that there is an inhibition preceding the movement of the eye, thus "it is not the proprioceptors of the eye muscles which cause the visual system to be 'blind' during eye-movements, but rather that the 'blind mind' allows the eye to start its movement" (page 261). There was also no indication of an increased threshold at the end of the movement, but at lower flash intensities, the chance of perception probability curve was slower in returning to unity. Ditchburn (1955) reports that stimuli initiated during involuntary saccades fail to be perceived, and presents evidence that retinal smearing is not the answer.

From the above it can be concluded that there is indisputable evidence for some form of central inhibition of impulses coming from the retina during eyemovement, but the extent of this inhibition is obviously still in some doubt. The difference in time interval between the end of the eye-movement and the reappearance of perception under the conditions of normal visual input, and that of an intense after-image has still to be accounted for. Fiorentini and Mazzantini (1965) maintain that this is possibly due to the latter being localized in a fixed retinal area: if the sensitivity to a fresh stimulus is still somewhat depressed at the end of the movement, then perhaps a longer time is required for the response to recover when the intensity and location of the stimulus are virtually invariant.

Another explanation can be found in Barlow's (1963) hypothesis concerning the visibility fluctuations of a stabilized image. The suggestion is that the stabilized stimulus is presenting the brain with contradictory information. A slowly adapting or non-adapting channel picking up from large receptive fields indicates the presence of the object, while a rapidly adapting channel, which signals changes in illumination from small regions, indicates that there is nothing present, there being no contour movement (due to the object being stabilized). Perception therefore consists of the alternation of the conflicting information and then eventual compromise resulting in a final dim cloudy appearance. As an after-image is also stabilized relative to the retina, eyemovement fails to elicit impulses in the latter channel, thus presenting the brain with contradictory information and facilitating the after-image's disappearance. Fiorentini and Mazzantini (1965) also point out that as the periods of invisibility of an after-image which follow an eyemovement are shorter than those following a spontaneous disappearance, a reflex inhibition related to the movement is favoured. As retinal smearing can be ruled out as being a possible reason for an after-image disappearing when the eye makes a movement in excess of a certain size or rate, the disappearances of the after-images during eyemovement in the present study can therefore be put down to a form of central inhibition, but such a 'reflex inhibition' is unlikely to be the reason for after-image disappearances, when there is little or no marked eyemovement. Possible mechanisms for this contingency will be dealt with in section 7.2.3.

7.2.2. Relationship of the after-images to stabilized retinal images

It is virtually imperative (in order to put the present findings into the context of previous investigations using conventionally stabilized retinal images) that consideration be given as to how comparable are flash stabilized after-images to images stabilized under conditions of invariant stimulation.

Barlow and Sparrock (1964) have studied this problem in their investigations which were designed to ascertain the role of after-images in dark adaptation. They matched the brightness of a stabilized annulus to that of an eccentrically positioned circular disc after-image, lying within the annulus: after each match, they also determined the threshold of the after-image using a flashing stimulus light. Now Barlow (1964) has put forward the notion that following light stimulation, the resulting bleached pigments in the photoreceptors makes them "noisy" in the dark, this being the cause of their low absolute sensitivity during the initial phases of dark adaptation. This persistent noise of the receptors in darkness is suggested as being equivalent to the activity produced by light and may be considered as the "equivalent background" light of Crawford (1937): its level in the dark exponentially decreases as the photoreceptive pigments regenerate in the course of dark adaptation. It is perhaps difficult to comprehend how this noise can be subjectively bright enough to be the equivalent background light of dark adaptation, but if one remembers that this equivalent light is localized in a fixed retinal area (i.e. is an after-image) and will therefore probably behave more like a stabilized light stimulus than a 'normal' one (in so far that a stabilized image quickly fades), then one can understand why this noise will subjectively not appear to be very bright.

Barlow and Sparrock (1964), in testing this hypothesis, found that they could get good matches between the above mentioned disc after-image and the stabilized annulus. Quantitatively they also verified Barlow's (1964) hypothesis by showing that there was no significant difference, either in the shapes of the curves (log retinal illumination/time), or in the absolute values between the "equivalent background" light and the equivalent luminance of the positive after-image (obtained from the stabilized image that matched it): the values for the "equivalent background" light were derived from the logarithm of the threshold (arbitrary unit) during dark adaptation and the logarithm of increment of threshold (same arbitrary unit) as a function of logarithm of background (in trolands).

A subjective assessment was also made by Barlow and Sparrock (1964) as to how similar an after-image and a stabilized retinal image appear when each is viewed by itself. They observed the behaviour of two squares, one on either side of the fovea, one a stabilized image, the other an after-image. If initially they appear of equal brightness, then the subjective appearances (fading, disappearance and reappearance, etc.) of the two squares is very similar. It is also found that a stabilized retinal image appears negative under the same conditions that an after-image appears negative, i.e. when viewed against a background of increased brightness, though an initial colour difference is noticeable. According to Barlow and Sparrock, the fact that the stabilized retinal image appears dimmer, even though the actual intensity of light falling on it is higher, can be explained if "fading corresponds to the reduction of amplification rather than to the passive decline of signals in a linear system" and "is caused by a mechanism analogous to 'automatic brightness control'," i.e. a feedback system actuated equally by genuine light evoked signals and noise signals from bleached photoreceptors.

From the above, it would appear that a stabilized image, matched in subjective brightness to an 'identical' after-image, behaves very similarly, in that the after-image is subject to almost identical fading, disappearances and reappearances, the counterpart of a negative after-image also being reproducible under similar conditions. The fact that a stabilized retinal image can be matched to an after-image throughout its duration suggests that an after-image is virtually equivalent to a stabilized retinal image whose intensity is decreasing exponentially, thus giving one grounds for assuming that the phenomena found in this present study using flash after-images are very similar to what would be found if the configurations had been 'perfectly' stabilized using a technique having an invariant light stimulus.

7.2.3. Localization of the phenomena associated with the flash stabilized after-images

If one can assume from section 7.2.2. that flash stabilized after-images are in many ways similar to conventionally stabilized images, then the fluctuations in appearance and fading found with after-images in this and other investigations (i.e. Bennet-Clark and Evans, 1964) are likely to have the same locus. On these grounds it is, therefore, first necessary to consider in some detail the localization of these effects in conventionally stabilized images, and the locus of the phenomena associated with after-images, before considering these effects in flash stabilized after-images.

Fiorentini and Ercoles (1963) have shown that the intensity of the process underlying the visibility of a stabilized test line drops rapidly during the first few seconds of observation, reaching a minimum in under ten seconds and then fluctuates in value while decaying much more slowly. This suggested to them that two different processes were involved, the first being responsible for the rapid initial decay in sensitivity which then persists at a much reduced rate, while the second process is one which fluctuates, with a period of several seconds, and accounts for the recurrent phases of visibility of the stabilized object. Similar findings have been reported by Eckman and Lindman (1964) when studying the time course of visibility of an after-image, and are taken by Fiorentini and Ercoles (1965) as indicating that the fluctuating components of their (1963) curves cannot be explained simply on the basis of recurring destabilization, but have a physiological origin.

Fiorentini and Ercoles (1963) suggest that, as the first process has a time course typical of adaptation, it could be identified with the fading process of Troxler's Effect, investigated by Clarke (1960). Localization of Troxler's Effect has been attempted by Clarke and Belcher (1962): a retinal locus was ruled out after a consideration of quantum statistics and the kinetics of local adaptation at the low level of stimulus intensity used, and a pre-cortical origin was suggested by the finding that there was no binocular interaction of the effect. After applying Poisson statistics to the results of an experiment involving saccadic displacements of a faded image in the light adapted condition, they obtained a frequency of seeing curve, from which they deduced that at least three of the functional units involved need to respond to enable the faded image to reappear: thus they suggested the lateral geniculate body as the probable seat of Troxler's Effect. However, Fiorentini and Ercoles (1965) then considered that the time course of this first process was perhaps more typical of the neural adaptation mentioned by Barlow (1964), than of photochemical adaptation, and that their findings support Barlow's (1963) hypothesis that border-contrast perception is mediated by neural units having a rapid course of adaptation under invariant stimulation.

The second (fluctuating) process, mentioned by Fiorentini and Ercoles (1963, 1965), is thought to be of central origin. That central effects are contributive to the disappearance of stabilized retinal images can be derived from the following findings. MacKay (1960) found that a stabilized line disappeared as a whole when an unstabilized background was introduced, reappearing on its removal. As a retinal theory might have predicted that the addition of an unstabilized background would revive activity in neighbouring receptors, a more central origin seems likely. As previously mentioned, Krauskopf and Riggs (1959) have found a reduction in stabilized visibility due to previous identical stimulation falling on the corresponding part of the contralateral eye, thus perhaps demonstrating some form of central adaptation, while Cohen (1961) has shown an increase in the stabilized visibility of a line, the closer an unstabilized line (seen in the other eye) is to it, in terms of retinal angle, thus showing possible neural interaction in the visual cortex. However, some care must be exercised before interpreting the effects of interocular transfer as indicating central involvement, as Day (1958) has pointed out that, as the monocular visual fields overlap, the fact that stimulation in one eye is affected by previous corresponding stimulation in the other eye does not, in itself, serve as evidence for a central locus of the phenomenon. Impulses may still be arriving from the initially stimulated area due to the formation of an after-image, whose later presence may be difficult to detect, these impulses being projected to the same area of the cortex, so this qualification perhaps applies most to the above mentioned finding of Krauskopf and Riggs (1959). Nevertheless, Brown (1962) has shown complete interocular transfer in the increase in rate of apparent change for the perceptual fluctuations which occur with a moving ambiguous figure, and is of the opinion that this central adaptation process may be partly responsible for the behaviour of stabilized retinal images.

Gerrits et al. (1966) also favour a cortical location for the disappearance of a stabilized image (they do not, however, agree to 'spontaneous' reappearances of a stabilized image). They point out that Granit (1947) has found that some of the retinal ganglion cells respond continuously to constant illumination, while Burns et al. (1962) have found that stationary, continuously illuminated 'patterns' produced no detectable influence upon the behaviour of cortical neurones except at ON and OFF, at which time these units would be driven away from their mean frequency of discharge for a short period. Thus the fading of a stabilized retinal image is most likely to be due to the lack of change in afferent stimulation reaching the cortical neurones. Gerrits et al. also point out that the linear fragmentation found by Pritchard et al. (1960) and others may have correlates in the fixed form and direction sensitive units found by Hubel and Wiesel (1959, 1962, 1963) in the cortex of the cat and monkey, thus ruling out a pre-cortical location.

For completeness it is worth mentioning a third process invoked by Fiorentini and Ercoles (1965) to account for the progressive increase in the rate of initial decay, as the number of previous presentations of the stabilized stimulus increases. This third process has a time course which is relative to the duration of the observations, and of the interval between observations. However, neural adaptation cannot easily explain the decreasing effectiveness of re-illumination in 'regenerating' a sharply defined image, so they postulate that "the boundary between the stimulated area and the background becomes progressively less defined at the receptor level as the time of stimulation increases, irrespective of the interruption of the stimulus" (page 13). They find evidence for this suggestion in Brindley's (1962) finding that the progressive blurring of detail in an after-image produced by a brief high intensity flash can be explained by assuming that some of the products of photolysis diffuse out from the receptors and reduce the sensitivity of their neighbours, the rate of diffusion being unaffected by steady or intermittent illumination of the retina.

If, as is likely, the photochemical effects of a previous stabilized stimulus take longer to return to 'normal' than neural effects, then these photochemical effects would tend to be summed with subsequent periods of stabilized stimulation, and thus cause a progressive blurring of the image. Barlow (1963) also hypothesises a diffusion process to account in part for the initial loss of detail observed during the first few seconds of stabilization; however, this latter diffusion process would require a diffusion rate far faster than has as yet been found in the human retina (i.e. Brindley, 1962). However, as Fiorentini and Ercoles (1965) point out, the diffusion hypothesis could explain why fine detail in a stabilized image permanently disappears after a certain duration (i.e. Riggs, Ratliff, Cornsweet and Cornsweet, 1953), and can be made to reappear by movement, but not by intermittent illumination (i.e. Campbell and Robson, 1961).

Attempts to localise after-images have resulted in evidence for both a peripheral and a central locus. Craik (1940) found that an after-image was visible in an eye which had been temporarily blinded by pressure on its upper outer edge, during exposure to a light source, and concluded that the origin of after-images was retinal, but did not deny that central processes may exert inhibitory influences on them: this deduction has changed little with the passage of time.

That after-images are subject to central modification has been shown by the following investigators: Misiak and Lozito (1951), who found increased latency and duration with binocular after-images; Popov and Popov (1953, 1954), who found that it was possible to evoke the appearance of after-images to verbal conditioned stimuli; Urist (1959), who found that subjects with their eyes closed were able to vary the size of an after-image by imagining that they were converging or diverging their eyes; Evans and Smith (1964), who found that a patterned after-image depressed cortical alpha rhythm for longer than a 'plain' after-image; Evans and Robertson (1965), who, recording from single cells in the cortex of paralysed cats, found that very intense light flashes produced maintained increases in their rate of firing which was shown to be not dependent on continuous retinal excitation.

Brindley (1959) has found that late foveal after-images (i.e. those excluding the first 15 seconds) produced by stimuli having a duration between 15.7 m.sec. and 1.68 sec. are a function solely of the total quantity of light energy delivered: from this finding he argues that the persistence of these late after-images depends on photochemical effects, within the receptors, of the absorption of light: adaptational changes in nerve cells are discounted. However, no mention is made of the fluctuation in appearance that is found with after-images (cf. Bennet-Clark and Evans, 1963; Ekman and Lindman, 1964) but some form of neural interaction is admitted during the first fifteen seconds of the after-image. For exposure durations (t) between 1.25 and 143 milli seconds, at two intensities (I), 2.6×10^5 and 2.6×10^6 trolands, Alpern and Bar (1962) found that the duration of the after-image was a function of the energy (It) of the inducing flash, and explained its final disappearance as the product of a photochemical reaction falling to some threshold value.

From the above there is therefore little reason to deviate much from Craik's (1940) conclusion in that, although after-images are primarily retinal in origin, they are subject to some form of cortical control; this cortical control is, however, likely to be the determinant of the fluctuations in appearance found in this and other after-image investigations, and may be partly responsible for some of the 'fading'.

7.3. Conclusions

There would appear to be no single hypothesis to explain all of the findings in the present study: a hypothesis based on the 'linear' receptive fields of cortical cells, found in the cat and to a lesser extent in the monkey (Hubel and Wiesel, 1959, 1962, 1965), has been shown [as being] to be a possible explanation for the results obtained on vertical parallel line interaction as a function of separation distance, line stability as a function of orientation, and, when coupled to the findings on the functional linking of lines very close to the vertical meridian (Choudhury *et al*., 1965), vertical parallel line interaction as a function of foveal placement. This hypothesis, however, fails to explain the lack of any significant differences in the study on line interaction as a function of orientation, when the variable is a diagonal; a 'novel' hypothesis was shown to be unlikely, at least in conjunction with the above mentioned supposition. Nevertheless, the receptive field cell hypothesis can also explain the increased visibility of the two parallel lines (relative to the diagonal) in the configuration consisting of two vertical parallel lines with an interposed 45° diagonal.

A purely retinal hypothesis, concerned solely with the increasing density of cones per unit area as one approaches the centre of the fovea, seemed to be valid when applied to single vertical bars at varying distances from the centre of the fovea. It was, however, shown to be an unlikely explanation of the findings on vertical parallel line interaction as a function of separation distance: it could nevertheless account for the findings on line interaction as a function of orientation and line stability as a function of orientation, as the number of cones stimulated by each bar would remain constant. However, this 'cone density' hypothesis fails to explain the findings on vertical parallel line interaction as a function of foveal placement and those using the N configuration: an explanation in terms of 'radial retinal inhibition' also seems rather unlikely. A relatively crucial test between a 'retinal inhibition' hypothesis and the 'central, vertical meridian' hypothesis was implemented and this seemed to indicate that the latter was more likely to be viable.

On a more general level, but related to the study as a whole, it can be safely assumed that when a retinal image is 'perfectly' stabilized, its contrast diminishes rapidly, but as to whether it then disappears completely (Yarbus, 1956; Ratliff, 1958; Campbell and Robson, 1961; Cornsweet, 1962; Millodot, 1956; Gerrits _et al_., 1966) or fluctuates in appearance (Barlow, 1963; Ditchburn, 1963; Fiorentini and Ercoles, 1963), is still a matter of some controversy. If such fluctuations are not an artifact of the stabilization procedure utilized, then it is most likely that they are central in origin, as it has already been pointed out that some of the retinal ganglion cells respond continuously to constant illumination (Granit, 1947), while cortical neurones only seem to show changes in their mean frequency of discharge when their level of input is changed (Burns _et al_., 1962). However, another possible source of change is the lateral geniculate body, where Arden and Soderberg (1961) have found periodical changes in the frequency of the resting discharge. As the authors are of the opinion that these discharge cycles are controlled by a reticulo-geniculate input (they are also, as expected, a function of afferent retinal impulses), then, in the absence of a change in retinal stimulation, these rhythmic changes in resting discharge would occur and are likely to be dependent upon level of arousal: this notion is in keeping with the findings mentioned in section 3.1.4. concerning changes in the visibility of a stabilized image as a function of stimulation in the other sense modalities, or shift in area of interest.

As an after-image appears to behave very similarly to a stabilized retinal image, whose subjective brightness is initially matched to it (Barlow and Sparrock, 1964), the fluctuations in its appearance are most probably due to the central mechanism outlined to account for the fluctuations found with stabilized retinal images (section 7.2.3.). The fact that an after-image's frequency of disappearance is initially lower than that of a stabilized retinal image is likely to be due to the initially fast regeneration of bleached receptor pigment, thus effecting considerable change in the receptor's rate of discharge, it being hypothesised that, in its later stages, an after-image's fluctuations in appearance are due to these changes in afferent retinal impulses levelling out, and the above mentioned cortical mechanism becoming operational.

The finding that those subjects with E scores greater than 14 tend to have significantly less 'trend reliability' than those with scores under this value, indicates that it is initially worthwhile discarding those potential subjects having E scores in excess of 14, when performing experiments in this area.

So far in the discussion, there has been deliberate omission of further reference to Gestalt and Hebbian theory because it was thought at this stage that Gestalt theory could offer little more than global, descriptive rationalizations as to the results of this set of investigations, whereas the type of theoretical approach outlined in this discussion is probably nearer to reality. As regards Hebbian theory, those aspects of it which are relevant to this study (cell assemblies and phase sequences) are perhaps best taken as being synonymous with the simple and complex cells found by Hubel and Wiesel (cf. Hebb, 1963), and have been given considerable coverage in this chapter.

8. SUMMARY

8. SUMMARY

The retinal image stabilizing technique of flash after-imagery was utilized in a systematic investigation of simple, foveally-stabilized linear configurations, as it was the only procedure which eliminated possible destabilization and yet gave a reasonable choice as to target structure. Four closely related topics were chosen for investigation, using monocular vision in the 'dominant' eye:

1) Vertical parallel line interaction as a function of separation distance, it being predicted from analogous investigations that, as the two lines became closer together, there would be an increase in simultaneous visibility and change frequency, and a corresponding decrease in single activity;

2) Vertical parallel line interaction as a function of foveal placement, where it was thought that, on the basis of cortical anatomical findings, there would be differences in their behaviour depending on whether the two lines fell together on either half of the visual field, or symmetrically, one on each half;

3) Line interaction as a function of orientation, it being predicted on physiological and psychological grounds that a vertical and a diagonal line would be less 'perceptually stable' than two verticals or a vertical and a horizontal line;

4) Line stability as a function of orientation, where it was predicted on physiological grounds that there would be no differences.

The lines were flashed as bar stimuli on to the rod-free area of the fovea, and from the analysis of the recordings of the resulting after-image 'behaviour' it was found that predictions 1) and 4) were verified. Hypothesis 2) was somewhat modified as the significant finding was that the inner bar of the two offset configurations was found to be relatively less 'perceptually stable', the finding being explicable in terms of the functional connections found between area 18 in both hemispheres, corresponding to that part of the visual field lying on either side of the vertical meridian. No differences in 'behaviour' were found in 3) for the diagonals, but in terms of presentation order, a significant increase in visibility was found for the variable lines.

Extraversion/introversion, neuroticism and level of arousal were also investigated, and a significant negative relationship was found between extraversion and 'trend reliability'.

Detailed discussion was given as to the following: (a) the inhibition of the after-images by eyemovement, showing that it was of some importance in the present study; (b) the relationship of the after-images to other forms of stabilized retinal images, thus enabling the relation of the present findings to those using conventional stabilizing techniques; (c) the localization of the phenomena associated with stabilized retinal images and after-images, thus giving an indication as to the locus of certain aspects of the phenomena found in this particular investigation.

9. REFERENCES

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ALPERN, M. (1962). The Eye, Vol. III, Chapter 5, edited by H. Davson. Academic Press, New York, London.

ALPERN, M., and BARR, L. (1962). Durations of the after-images of brief light flashes and the theory of the Broca-Sulzer phenomenon. J. Opt. Soc. Am., 52, 219-221.

ARDEN, G.B., and SODERBERG, U. (1961). The transfer of optical information through the lateral geniculate body of the rabbit. Sensory Communication, edited by Rosenblith, W.A. John Wiley, New York.

BARLOW, H.B. (1963). Slippage of contact lenses and other artifacts in relation to fading and regeneration of supposedly stable retinal images. Quart. J. Exp. Psychol., 15, 36-51.

BARLOW, H.B. (1964). Dark-adaptation: a new hypothesis. Vision Res., 4, 47-58.

BARLOW, H.B., and SPARROCK, J.M.B. (1964). The role of after-images in dark adaptation. Science, 144, 1309-1314.

BEELER, G.W., FENDER, D.H., NOBEL, P.S., and EVANS, C.R. (1964). Perception of pattern and colour in the stabilized retinal image. Nature, 203, 1200.

BENNET-CLARK, H.C., and DITCHBURN, R.W. (1963). The effect of reduced pressure on the fit of contact lenses. Optica Acta, 10, 367.

BENNET-CLARK, H.C., and EVANS, C.R. (1963). Fragmentation of patterned targets when viewed as prolonged after-images. Nature, 199, 1215-1216.

BONEAU, C.A. (1960). The effects of violations of assumptions underlying the t test. Psychol. Bull., 57, 49-64.

BRINDLEY, G.S. (1959). The discrimination of after-images. J. Physiol., 147, 194-203.

BRINDLEY, G.S. (1962). Two new properties of foveal after-images and a photochemical hypothesis to explain them. J. Physiol., 164, 168-179.

BROWN, K.T. (1962). Complete interocular transfer of an adaptation process responsible for perceptual fluctuations with an ambiguous visual figure. Vision Res., 2, 469-475.

BRYDEN, M.P. (1960). Tachistoscopic recognition of non-alphabetical material. Canad. J. Psychol., 14, 78-86.

BURNS, D.B., HERON, W., and PRITCHARD, R. (1962). Physiological excitation of visual cortex in cat's unanaesthetized isolated forebrain. J. Neurophysiol., 25, 165-181.

BYFORD, G.H. (1962). The fidelity of contact lens movement recording. Optica Acta, 9, 223-236.

CAMPBELL, F.W., and ROBSON, J.G. (1961). A fresh approach to stabilized retinal images. J. Physiol., 158, 1-11.

CAMPBELL, F.W., ROBSON, J.G., and WESTHEIMER, R.G. (1959). Fluctuations of accommodation under steady viewing conditions. J. Physiol., 145, 579-594.

CHOUDHURY, B.P., WHITTERIDGE, D., and WILSON, M.E. (1965). The function of the callosal connections of the visual cortex. Quart. J. Exp. Physiol., 50, 214.

CLARKE, F.J.J. (1960). A study of Troxler's Effect. Optica Acta, 7, 219-236.

CLARKE, F.J.J. (1961). Visual recovery following local adaptation of the peripheral retina (Troxler's Effect). Optica Acta, 8, 121-135.

CLARKE, F.J.J., and BELCHER, S.J. (1962). On the localization of Troxler's Effect in the visual pathway. Vision Res., 2, 53-68.

CLOWES, M.B. (1962). A note on colour discrimination under conditions of retinal image constraint. Optica Acta, 9, 65-68.

CLOWES, M.B., and DITCHBURN, R.W. (1959). An improved apparatus for producing a stabilized retinal image. Optica Acta, 6, 252-265.

COHEN, H.B. (1961). The effect of contralateral visual stimulation on visibility with stabilized retinal images. Canad. J. Psychol., 15, 212-219.

COHEN, W. (1958). Color perception in the chromatic Ganzfeld. Amer. J. Psychol., 71, 390-394.

CORNSWEET, T.N. (1956). Determination of the stimuli for involuntary drifts and saccadic eye movements. J. Opt. Soc. Amer., 46, 987-993.

CORNSWEET, T.N. (1962). A stabilized image requiring no attachments to the eye. Amer. J. Psychol., 75, 653-656.

CRAIG, E.A., and LICHTENSTEIN, M. (1953). Visibility-invisibility cycles as a function of stimulus-orientation. Amer. J. Psychol., 66, 554-563.

CRAIK, K.J.W. (1940). Origin of visual after-images. Nature, 145, 512.

CRAWFORD, B.H. (1937). The change of visual sensitivity with time. Proc. Roy. Soc. B, 123, 69-89.

CRAWFORD, B.H. (1946). Photochemical laws and visual phenomena. Proc. R. Soc. B, 133, 63-75.

CURTIS, H.J. (1940). Intercortical connections of corpus callosum as indicated by evoked potentials. J. Neurophysiol., 3, 407-413.

DANIEL, P.M., and WHITTERIDGE, D. (1961). The representation of the visual field on the cerebral cortex in monkeys. J. Physiol., 159, 203-221.

DAY, R.H. (1958). On interocular transfer and the central origin of visual after-effects. Amer. J. Psychol., 71, 784-790.

DICARA, L., and BARMACK, J.E. (1965). The effect of reporting procedures on the stabilized retinal image. J. Psychol., 59, 55-60.

DITCHBURN, R.W. (1955). The stabilized retinal image. Optica Acta, 2, 128-133.

DITCHBURN, R.W., and FENDER, D.H. (1955). The stabilized retinal image. Optica Acta, 2, 128-133.

DITCHBURN, R.W., FENDER, D.H., and MAYNE, S. (1959). Vision with controlled movements of the retinal image. J. Physiol., 145, 98-107.

DITCHBURN, R.W., FENDER, D.H., MAYNE, S., and PRITCHARD, R.M. (1956). A stabilized retinal image of the iris. Proc. Phy. Soc. B, L, xlx, 1165.

DITCHBURN, R.W., and GINSBORG, B.L. (1952). Vision with a stabilized retinal image. Nature, 170, 36.

DITCHBURN, R.W., and GINSBORG, B.L. (1953). Involuntary eye-movements during fixation. J. Physiol., 119, 1-17.

DITCHBURN, R.W., and PRITCHARD, R.M. (1956). Stabilized interference fringes on the retina. Nature, 177, 434.

DUFFY, E. (1962). Activation and Behaviour. New York, Wiley.

DUKE-ELDER, S. (1961). System of Ophthalmology, Vol. 11. The anatomy of the visual system. Henry Kimpton, London.

ECKMAN, G., and LINDMAN, R. (1964). Measurements of the underlying process in perceptual fluctuations. Vision Res., 2, 253-260.

EVANS, C.R. (1965a). A universally fitting contact lens for the study of stabilized retinal images. Brit. J. Physiol. Optics, 22, 39-45.

EVANS, C.R. (1965b). Some studies of pattern perception using a stabilized retinal image. Brit. J. Psychol., 56, 121-133.

EVANS, C.R. (1966). Prolonged after-images employed as a technique for retinal stabilization: some further studies of pattern perception and some theoretical considerations. Automomics Division Report, No. 25.

EVANS, C.R., and PIGGINS, D.J. (1963). A comparison of the behaviour of geometrical shapes when viewed under conditions of steady fixation, and with apparatus for producing a stabilized retinal image. Brit. J. Physiol. Optics, 20, 261-273.

EVANS, C.R., and ROBERTSON, A.D.J. (1965). Prolonged excitation in the visual cortex of the cat. Science, 150, 913-915.

EVANS, C.R., and SMITH, G.K. (1964). Alpha-frequency of electroencephalogram and a stabilized retinal image. Nature, 204, 303-304.

EYSENCK, H.J., and EYSENCK, S.B.J. (1964a). Manual of the Eysenck Personality Inventory. Univ. London Press Ltd., London.

EYSENCK, H.J., and EYSENCK, S.B.J. (1964b). Eysenck Personality Inventory (Personality Questionnaire) Form A. Univ. London Press Ltd., London.

FENDER, D.H. (1955). Torsional motions of the eyeball. Brit. J. Ophthol., 39, 65-72.

FIORENTINI, A., and ERCOLES, A.M. (1960). Vision with stabilized images and intermittent illumination. Atti Fond. G. Ronchi, 15, 618-633.

FIORENTINI, A., and ERCOLES, A.M. (1963). Fluctuations of response to a stabilized visual stimulus. Atti Fond. G. Ronchi, 18, 548-560.

FIORENTINI, A., and ERCOLES, A.M. (1965). Adaptation to a stabilized stimulus. Atti Fond. G. Ronchi, 20, 580-592.

FIORENTINI, A., and ERCOLES, A.M. (1966). Involuntary eye movements during attempted monocular fixation. Atti Fond. G. Ronchi, 21, 199-217.

FIORENTINI, A., and MAZZANTINI, L. (1965). Inhibition of after-images due to voluntary eye movements. Atti Fond. G. Ronchi, 20, 307-320.

GERRITS, H.J.M., DE HAAN, B., and VENDRIK, A.J.H. (1966). Experiments with retinal stabilized images: relations between the observations and neural data. Vision Res., 6, 427-440.

GINSBORG, B.L. (1953). Small involuntary movements of the eye. Brit. J. Ophthal., 37, 746-754.

GRANIT, R. (1947). Sensory Mechanisms of the Retina. Oxford University Press, London, pp. 89 and 106.

GUILFORD, J.P. (1956). Fundamental statistics in psychology and education, 3rd edition. McGraw-Hill Book Co. Inc., New York.

GUILFORD, J.P. (1965). Fundamental statistics in psychology and education, 4th edition. McGraw-Hill Book Co. Inc., New York.

HALL, D.C. (1964). A further investigation into the supposed curvilinear relationship between stimulus emotionality and recognition threshold. B.Sc. Thesis, University of Edinburgh.

HAYS, W.L. (1963). Statistics for Psychologists. Holt Rinehart & Winston Inc., New York.

HEBB, D.O. (1949). Organization of Behaviour. Wiley, New York.

HEBB, D.O. (1955). Drives and the C.N.S. (Conceptual Nervous System). Psych. Rev., 62, 243-254.

HEBB, D.O. (1958). A Textbook of Psychology. W.B. Sanders Co., Philadelphia and London.

HEBB, D.O. (1959). In S. Koch (ed.), 'Psychology: A Study of a Science,' Vol. 1. McGraw-Hill, New York, pp. 622-643.

HEBB, D.O. (1963). The semiautonomous process: its nature and nurture. Amer. Psychol., 18, 16-27.

HECHT, S., HAIG, C., and WALD, G. (1936). Dark adaptation of retinal fields of different size and location. J. Gen. Physiol., 19, 321-337.

HECHT, S., HAIG, C., and CHASE, A.M. (1937). The influence of light adaptation on subsequent dark adaptation of the eye. J. Gen. Physiol., 20, 831-850.

HECKENMUELLER, E.G. (1965). Stabilization of the retinal image: a review of method, effects and theory. Psychol. Bull., 63, 157-169.

HOCHBERG, J., and HAY, J. (1956). Figural after-effect, after-image and physiological nystagmus. Amer. J. Psychol., 69, 480-482.

HUBEL, D.H., and WIESEL, T.N. (1959). Receptive fields of single neurones in the cat's striate cortex. J. Physiol., Lond., 148, 574-591.

HUBEL, D.H., and WIESEL, T.N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. J. Physiol., Lond., 160, 106-154.

HUBEL, D.H., and WIESEL, T.N. (1963). Shape and arrangement of columns in cat's striate cortex. J. Physiol., Lond., 165, 559-568.

HUBEL, D.H., and WIESEL, T.N. (1965). Receptive fields and functional architecture in two non-striate visual areas (18 and 19) of the cat. J. Neurophysiol., 28, 229-289.

KEESEY, U.K. (1960). Effects of involuntary eye movements on visual acuity. J. Opt. Soc. Amer., 50, 769-774.

KEESEY, U.T., and RIGGS, L.A. (1962). Visibility of mach bands with imposed motions of the retinal image. J. Opt. Soc. Amer., 52, 719-720.

KOFFKA, K. (1935). Principles of Gestalt Psychology. Harcourt, Brace, New York.

KOHLER, W. (1929). Gestalt Psychology. Liveright, New York.

KOHLER, W., and WALLACH, H. (1944). Figural after-effects: an investigation of visual processes. Proc. Amer. Phil. Soc., 88, 269-357.

KRAUSKOPF, J. (1957). Effect of retinal image motion on contrast thresholds for maintained vision. J. Opt. Soc. Amer., 47, 740-747.

KRAUSKOPF, J. (1963). Effect of retinal image stabilization on the appearance of heterochromatic targets. J. Opt. Soc. Amer., 53(c), 741-744.

KRAUSKOPF, J., and RIGGS, L.A. (1959). Interocular transfer in the disappearance of stabilized images. Amer. J. Psychol., 72, 248-252.

KUHN, H.S. (1950). Eyes and Industry, 2nd edition. Henry Kimpton, London.

LATOUR, P.L. (1962). Visual threshold during eye movements. Vision Res., 2, 261-262.

MACKAY, D.M. (1960). Monocular rivalry between stabilized and unstabilized images. Nature, 185, 834.

McKINNEY, J.P. (1963). Disappearance of luminous designs. Science, 140, 403-404.

MILES, W.R. (1930). Ocular dominance in human adults. J. Gen. Psychol., 3, 412-430.

MILLODOT, M. (1965). Stabilized retinal images and disappearance time. Brit. J. Physiol. Opt., 122, 148-152.

MILLODOT, M. (1966). Foveal and extra-foveal acuity with and without stabilized retinal images. Brit. J. Physiol. Opt., 23, 75-106.

MILNER, P.M. (1957). The cell assembly: Mark 11. Psychol. Rev., 64, 242-252.

MSIAK, H., and LOZITO, C.C. (1951). Latency and duration of monocular and binocular after-images. J. Exp. Psychol., 42, 247-249.

MYERS, R.E. (1962). Commissural connections between occipital lobes of the monkey. J. comp. Neurol., 118, 1-16.

NACHMIAS, J. (1959). Two-dimensional motion of the retinal image during monocular fixation. J. Opt. Soc. Amer., 49, 901-908.

PIGGINS, D.J. (1965). An investigation of the auto-kinetic effect employing an after-image. Brit. J. Physiol. Optics, 122, 143-147.

POPOV, N.A., and POPOV, C. (1953). Contribution à l'étude des fonctions corticales chez l'homme par la methode des reflexes conditionnes electro-corticaux. II. De la modification par l'alcool des couleurs des images consecutives et des images consecutives conditionnees. Comptes Rendus de l'Academie des Sciences, 237, 1439-1441.

POPOV, N.A., and POPOV, C. (1954). Contribution à l'étude des fonctions corticales chez l'homme par la methode des reflexes conditionnes electro-corticaux. V. Deuxieme systeme de signalisation. Compte Rendus de l'Academie des Sciences, 238[2], 2118-2120.

POLYAK, S. (1957). The Vertebrate Visual System. University of Chicago Press, ~~pp. 250-251~~.

PRITCHARD, R.M. (1958). Visual illusions viewed as stabilized retinal images. Quart. J. Exp. Psychol., 10, 77-81.

PRITCHARD, R.M. (1961a). A collimator stabilizing system for the retinal image. Quart. J. Exp. Psychol., 13, 181-183.

PRITCHARD, R.M. (1961b). Stabilized images on the retina. Scient. Amer., 204(6), 72-78.

PRITCHARD, R.M., HERON, W., and HEBB, D.O. (1960). Visual perception approached by the method of stabilized images. Canad. J. Psychol., 14, 67-77.

RATLIFF, F. (1952). The role of physiological nystagmus in monocular acuity. J. Exp. Psychol., 43, 163-172.

RATLIFF, F. (1958). Stationary retinal images requiring no attachments to the eye. J. Opt. Soc. Amer., 48, 274-275.

RATLIFF, F., and RIGGS, L.A. (1950). Involuntary motions of the eye during monocular fixation. J. Exp. Psychol., 40, 687-701.

RIGGS, L.A., ARMINGTON, E.C., and RATLIFF, F. (1954). Motions of the retinal image during fixation. J. Opt. Soc. Amer., 44, 315-321.

RIGGS, L.A., and RATLIFF, F. (1951). Visual acuity and the normal tremor of the eyes. Science, 114, 17-18.

RIGGS, L.A., RATLIFF, F., CORNSWEET, J.C., and CORNSWEET, T.N. (1953). The disappearance of steadily fixated visual test objects. J. Opt. Soc. Amer., 43, 495-501.

RIGGS, L.A., and TULANEY, S.U. (1959). Visual effects of varying the extent of compensation for eye movements. J. Opt. Soc. Amer., 9, 741-745.

SHERWOOD, J.J. (1965). A relation between arousal and performance. Amer. J. Psychol., 78, 461-465.

TEES, R.C. (1961). The role of field effects in visual perception. Undergrad. Res. Proj. Psychol., 3, 87-96.

URIST, M.J. (1959). After-images and ocular muscle proprioception. A.M.A. Arch. Ophthal., 61, 230-232.

VOLKMANN, F.C. (1962). Vision during voluntary saccadic eye movements. J. Opt. Soc. Amer., 52, 571-578.

WHITTERIDGE, D. (1965). Geometrical relations between the retina and the visual cortex. Mathematics and computer science in biology and medicine: Medical Research Council, 269-276.

WHITTERIDGE, D. (1967). Personal communication.

YARBUS, A.L. (1956). Perception of a stationary retinal image. Biofizika, 1, 435-437.

YARBUS, A.L. (1957a). A new method of studying the activity of various parts of the retina. Biofizika, 2, 165-167.

YARBUS, A.L. (1957b). The perception of an image fixed with respect to the retina. Biophysics, 2, No. 1, 683-690.

YARBUS, A.L. (1959). The perception of images moving across the retina at a fixed speed. Biophysics, 4, No. 3, 70-80.

YARBUS, A.L. (1960a). Perception of images of variable brightness fixed with respect to the retina of the eye. Biophysics, 5, No. 2, 183-187.

YARBUS, A.L. (1960b). Perception of images of great brightness, motionless with respect to the retina of the eye. Biophysics, 5, No. 3, 338-339.

10. APPENDICES

10.1. Energy Distribution of Flash Tube Discharge

10.2. Example of a Pen Record

10.3. Eysenck Personality Inventory

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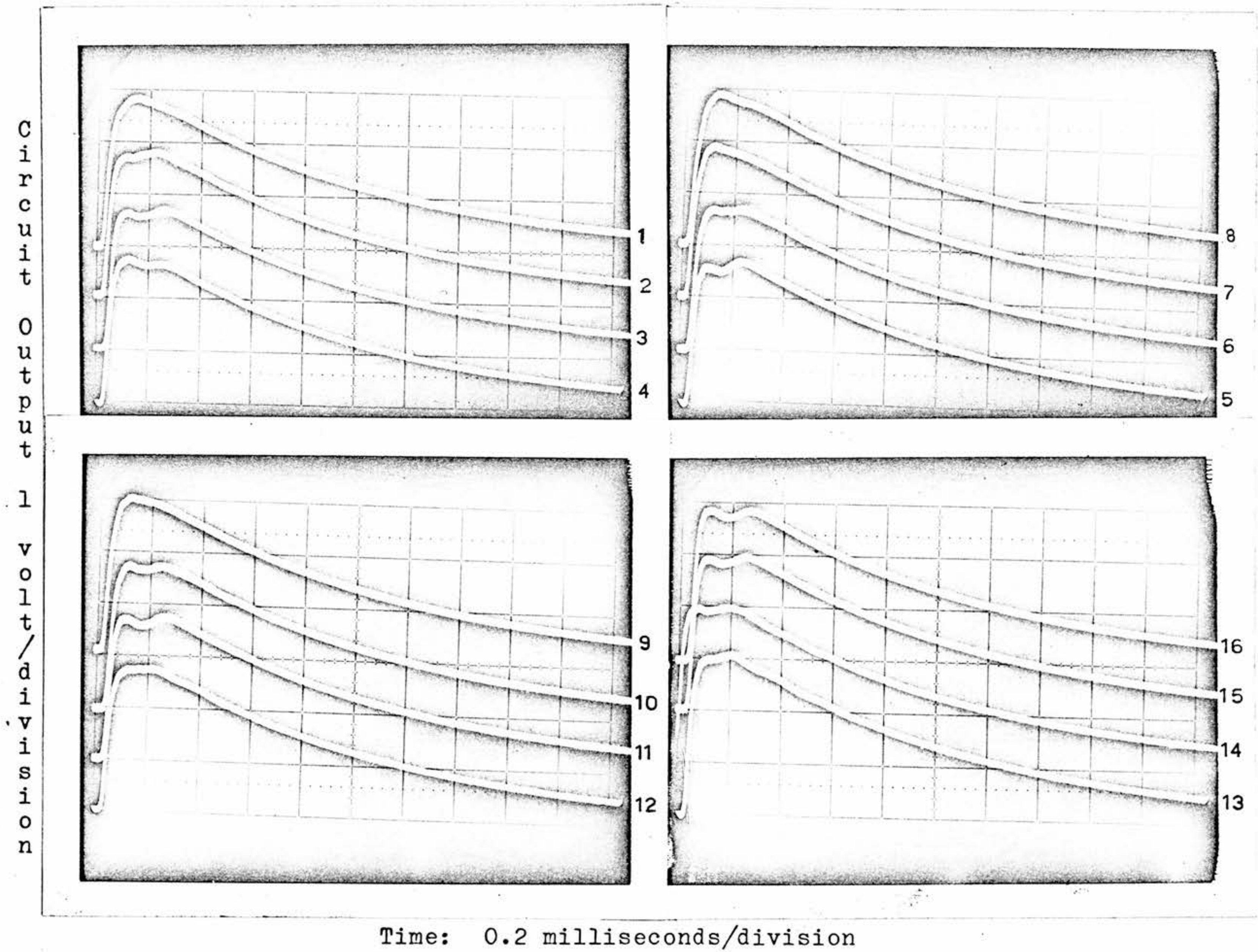
10.10. Two Vertical Parallel Lines with an Interposed 45° Diagonal

10.11. Review of SRI Phenomena from April 1967 to June 1969



<u>Figure 10.i.</u> Change in circuit output over time, for sixteen consecutive flash discharges.

10.1. Energy Distribution of Flash Tube Discharge*

The energy distribution over time of the flash tube was measured using a Mullard OCP71 phototransistor in a simple circuit coupled to a cathode ray oscilloscope, whose screen was photographed using a Polaroid land camera attachment: sixteen consecutive flashes are shown in Figure 10.i. It would appear from these records that about 66% of the light energy is emitted during the first millisecond, 27% during the second, the remaining 7% being emitted during the third millisecond (the curves having been extrapolated to obtain this last percentage). The actual amount of energy released on successive flashes would seem to vary by about ± 1%, this variation occurring during the first 0.4 millisecond.

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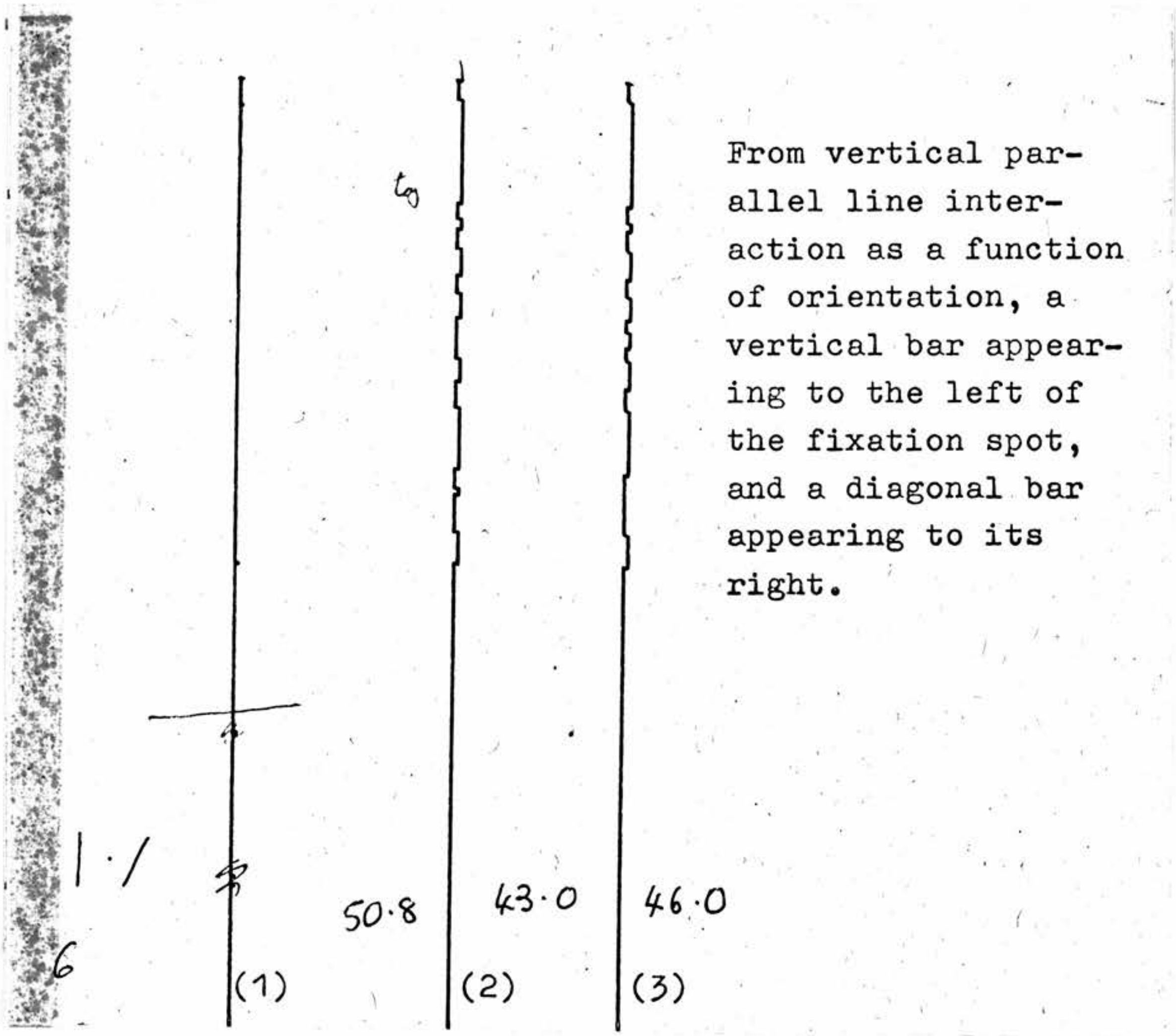
* This investigation was made in the Physics Department of Edinburgh University by Dr. Bradford and assistants.

10.2. Example of a Pen Record



(1) Flash marker and error marker channel.

(2) Vertical bar channel.

(3) Diagonal bar channel.

The figures at the bottom of the record are the vertical, simultaneous, and diagonal visibility times (secs.) respectively, as recorded on the electronic timers.

10.3. Eysenck Personality Inventory* (Form A)

The following items comprise the above questionnaire:

1. Do you often long for excitement?
2. Do you often need understanding friends to cheer you up?
3. Are you usually carefree?
4. Do you find it very hard to take no for an answer?
5. Do you stop and think things over before doing anything?
6. If you say you will do something do you always keep your promise, no matter how inconvenient it might be to do so?
7. Does your mood often go up and down?
8. Do you generally do and say things quickly without stopping to think?
9. Do you ever feel "just miserable" for no good reason?
10. Would you do almost anything for a dare?
11. Do you suddenly feel shy when you want to talk to an attractive stranger?
12. Once in a while do you lose your temper and get angry?
13. Do you often do things on the spur of the moment?
14. Do you often worry about things you should not have done or said?
15. Generally, do you prefer reading to meeting people?
16. Are your feelings rather easily hurt?
17. Do you like going out a lot?
18. Do you occasionally have thoughts and ideas that you would not like other people to know about?
19. Are you sometimes bubbling over with energy and sometimes very sluggish?
20. Do you prefer to have few but special friends?

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* Eysenck (1964).

21. Do you daydream a lot?

22. When people shout at you, do you shout back?

23. Are you often troubled about feelings?

24. Are <u>all</u> your habits good and desirable ones?

25. Can you usually let yourself go and enjoy yourself at a gay party?

26. Would you call yourself tense of "highly-strung"?

27. Do other people think of you as being very lively?

28. After you have done something important, do you often come away feeling you could have done better?

29. Are you mostly quiet when you are with other people?

30. Do you sometimes gossip?

31. Do ideas run through your head so that you cannot sleep?

32. If there is something you want to know about, would you rather look it up in a book than talk to someone about it?

33. Do you get palpitations or thumping in your heart?

34. Do you like the kind of work that you need to pay close attention to?

35. Do you get attacks of shaking or trembling?

36. Would you always declare <u>everything</u> at the customs, even if you knew that you could never be found out?

37. Do you hate being with a crowd who play jokes on one another?

38. Are you an irritable person?

39. Do you like doing things in which you have to act quickly?

40. Do you worry about awful things that might happen?

41. Are you slow and unhurried in the way you move?

42. Have you ever been late for an appointment or work?

43. Do you have many nightmares?

44. Do you like talking to people so much that you never miss a chance of talking to a stranger?

45. Are you troubled by aches and pains?

46. Would you be very unhappy if you could not see lots of people most of the time?

47. Would you call yourself a nervous person?

48. Of all the people you know, are there some whom you definitely do not like?

49. Would you say that you were fairly self-confident?

50. Are you easily hurt when people find fault with you or your work?

51. Do you find it hard to really enjoy yourself at a lively party?

52. Are you troubled with feelings of inferiority?

53. Can you easily get some life into a rather dull party?

54. Do you sometimes talk about things you know nothing about?

55. Do you worry about your health?

56. Do you like playing pranks on others?

57. Do you suffer from sleeplessness?

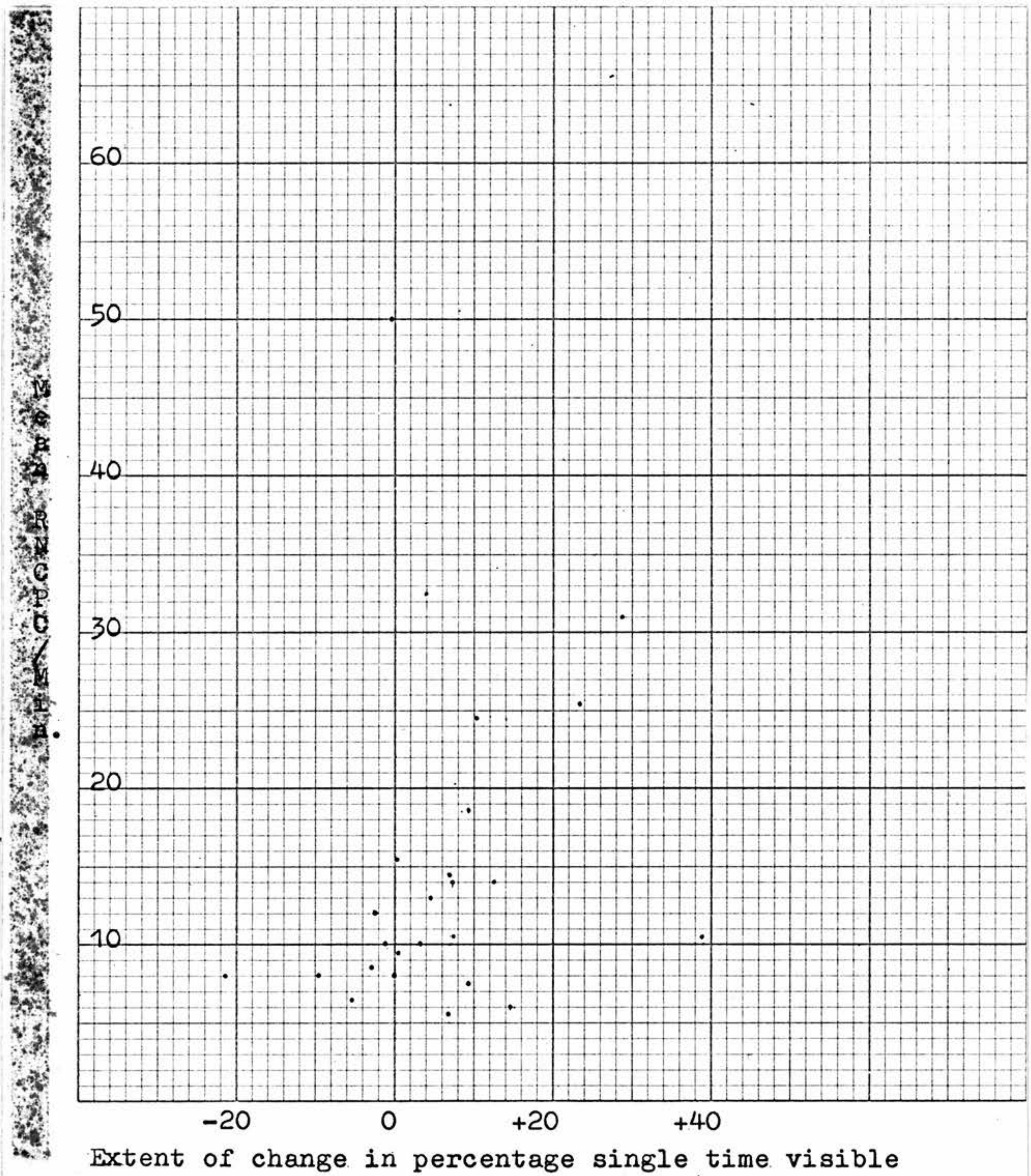
10.4. Graphs concerned with Rate of Necker Cube Perspective Change (RNCPC)

The three graphs overleaf relate the extent of change in three dimensions, namely,

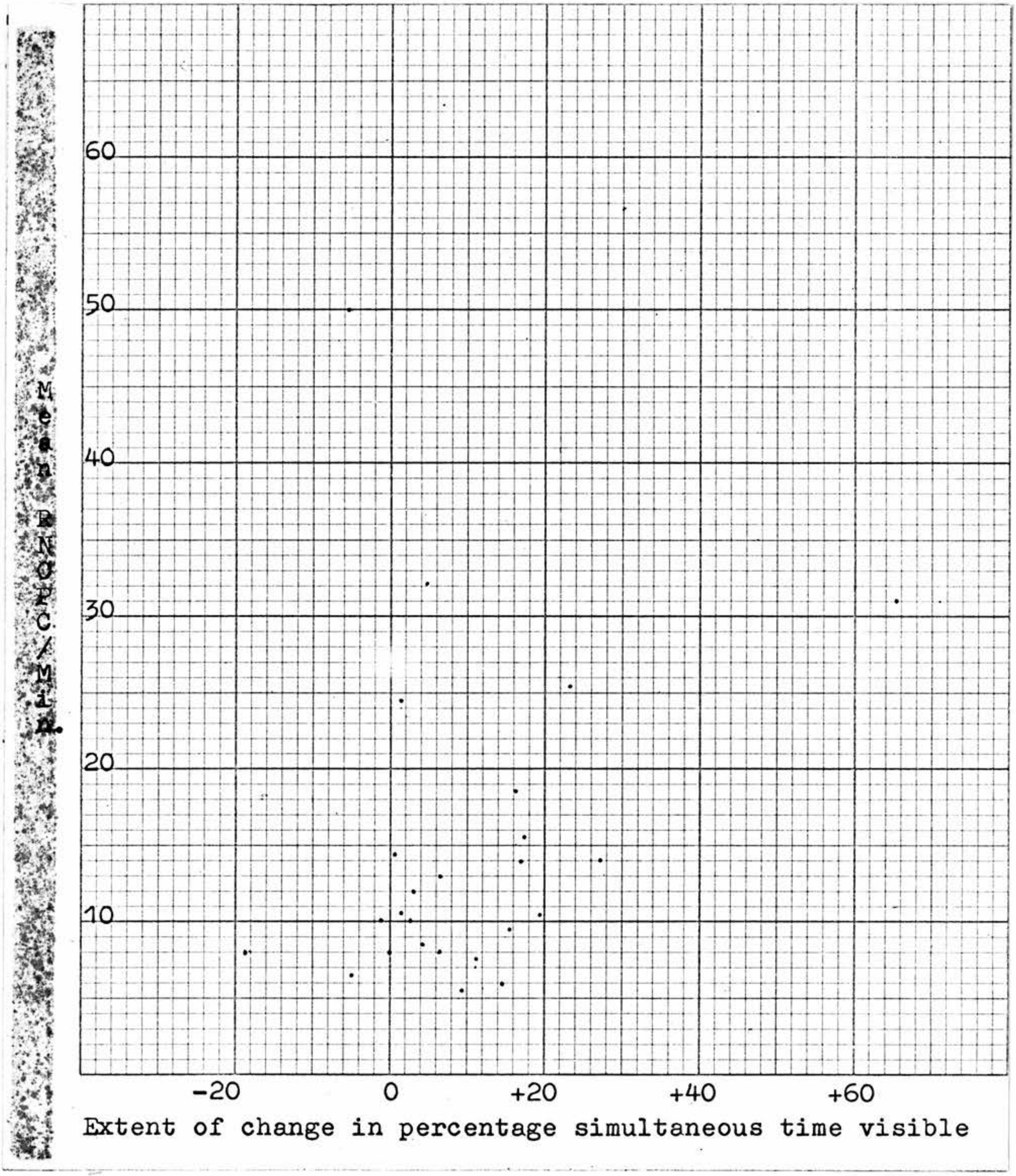
1) Percentage single time visible;
2) Percentage simultaneous time visible;
3) Single change frequency;

to the RNCPC/minute as the stimulus bars become closer together, for 24 subjects.

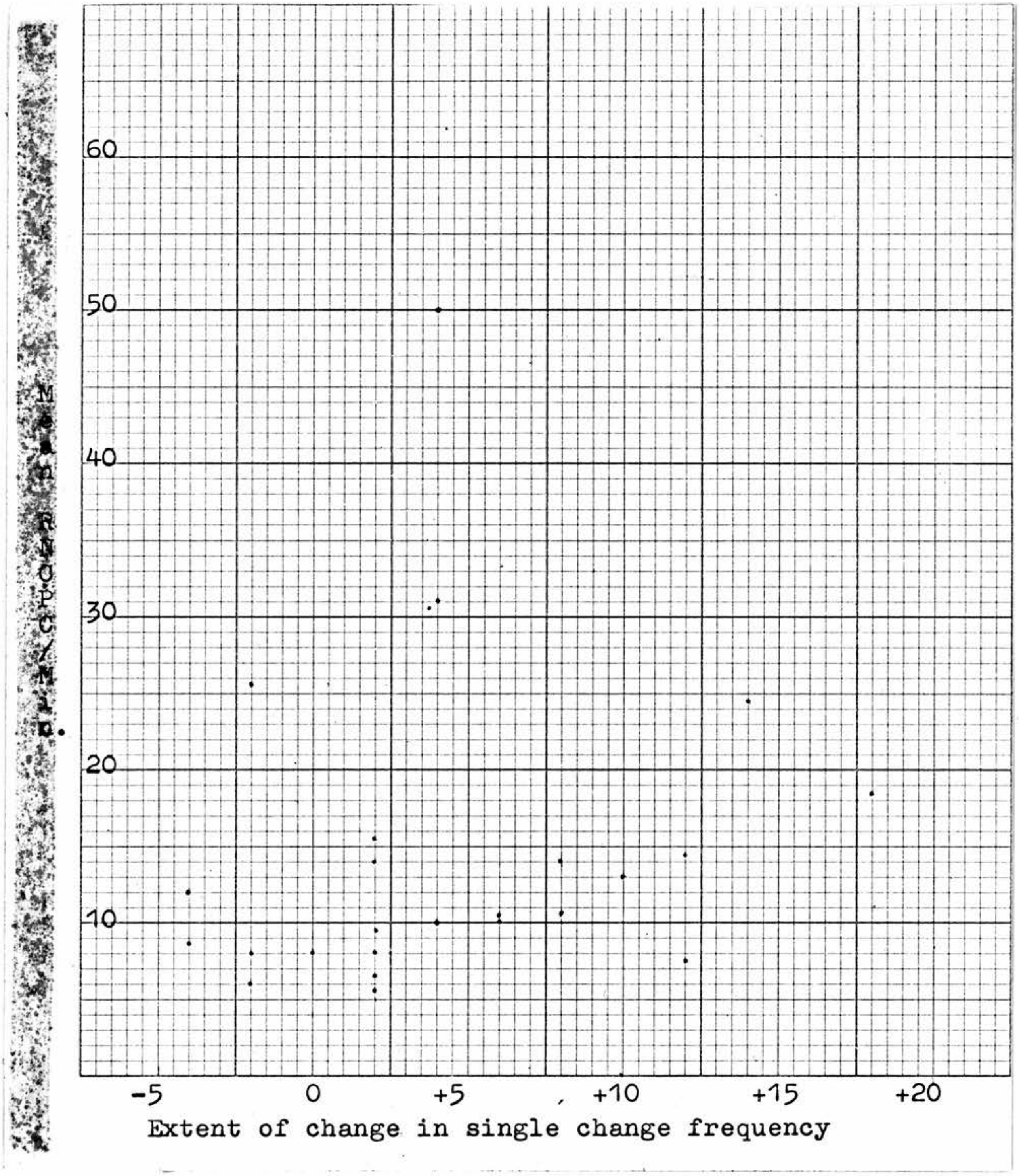
10.4.1. Graph of mean RNCPC/min. and extent of change in percentage single time visible.



10.4.2. **Graph of mean RNCPC/min. and extent of change in percentage simultaneous time visible.**



10.4.3. Graph of mean RNCPC/min. and extent of change in single change frequency.



10.5. Binocular Vision: Vertical Parallel Line Study

Stimulus bars, having a central separation distance of 10 mm., were viewed binocularly, and the results are compared below with those of identical configurations in experiments 1* and 2*, where they were viewed monocularly with the dominant eye.

		Right		Left	Sim.		Non-sim.
Mean %TV	(N = 25)	88.3		87.6	84.8		6.4
	(N = 54)*	(78.6)		(78.8)	(75.5)		(6.4)
	(N = 48)**	(81.3)		(81.6)	(78.4)		(6.1)
σ		12.8		13.2	14.4		7.7
		(17.3)		(16.1)	(17.0)		(6.2)
		(16.2)		(16.7)	(16.8)		(7.0)
Mean %CF		46.4	N.S.	53.6	61.5	N.S.	38.5
		(48.3)		(51.7)	(71.7)		(28.3)
		(51.3)		(48.7)	(65.8)		(34.2)
σ			12.3			29.4	
			(12.9)			(26.8)	
			(10.0)			(27.6)	

10.6. Non-dominant Eye: Vertical Parallel Line Study

Stimulus bars, having a central separation distance of 10 mm., were viewed with the non-dominant eye, and the results are compared below with those of identical configurations in experiments 1* and 2**, where they were viewed monocularly with the dominant eye.

		Right		Left	Sim.		Non-sim.
Mean %TV	(N = 17)	85.6		83.5	81.6		5.9
	(N = 54)*	(78.6)		(78.8)	(75.5)		(6.4)
	(N = 48)**	(81.3)		(81.6)	(78.4)		(6.1)
σ		10.7		9.9	10.3		7.3
		(17.3)		(16.1)	(17.0)		(6.2)
		(16.2)		(16.7)	(16.8)		(7.0)
Mean %CF		44.2	N.S.	55.8	63.3	N.S.	36.7
		(48.3)		(51.7)	(71.7)		(28.3)
		(51.3)		(48.7)	(65.8)		(34.2)
σ			11.9			30.6	
			(12.9)			(26.8)	
			(10.0)			(27.6)	

10.7. Horizontal Parallel Line Study

Horizontal stimulus bars, having a central separation distance of 40 mm., were viewed with the dominant eye, and the results are compared below with those of the identical, but vertically aligned configuration of experiment one, viewed under the same conditions.

		Upper (Right)	Lower (Left)	Sim.		Non-sim.
%TV	(N = 30)	76.0	76.9	71.7		9.4
	(N = 54)	(72.2)	(71.3)	(66.0)		(19.9)
σ		14.7	14.8	14.1		6.2
		(17.7)	(20.3)	(18.6)		(9.2)
%CF		52.0	48.0	55.8	N.S.	44.2
		(51.4)	(48.6)	(50.6)		(49.4)
σ		13.1			27.5	
		(10.3)			(25.6)	

10.8. Vertical Line Stability as a function of Distance from the Centre of the Fovea

This study utilized the same stimulus plates as the study on vertical parallel lines interaction as a function of separation distance, except that, in any given run, either all the right or left hand slots were masked. Initially one twenty-year-old male student served as a subject and performed twelve runs comprising of six runs of the four bars to the right and six to the left of the fixation point. The crucial experimental conditions were almost identical to those in the main experiment, except that a dental bite was used in order to give greater head stability during fixation. The results for the right and left conditions have been combined for mean percentage time visible and mean change frequency and are shown below.

	Distance of bar from central fixation spot (mm.)			
	40	30	20	10
Mean % Time Visible	80.01	89.83	90.54	91.78
σ	(8.99)	(4.57)	(6.33)	(9.17)
Mean C.F.	5.17	4.00	3.83	3.67
σ	(1.52)	(1.41)	(1.52)	(1.37)

The increase in the mean % T.V. as the bar becomes closer to the fixation spot is significant at beyond the 0.01 level (Friedman Two-way analysis of Variance by Ranks $X_r^2 = 13.7$, d.f. = 3), while the mean C.F. shows a non-significant decrease with decreasing distance from the fixation spot.

A subsequent, almost identical, study utilized six third year undergraduates (having E.P.I. E scores less than 14; see section 6.3.) who each performed four runs with the bars to the right on two occasions and to the left on the other two occasions. Again the results for the right and left conditions have been combined, but the results of the first two runs are shown separately from those of the last two.

Runs 1 and 2	Distance of bar from central fixation spot (mm.)			
	40	30	20	10
Mean % T.V.	57.94	65.52	65.55	72.03
σ	(14.96)	(12.20)	(13.15)	(10.96)
Mean C.F.	17.59	18.92	14.50	14.92
σ	(7.50)	(8.52)	(5.84)	(4.57)

Runs 3 and 4				
Mean % T.V.	69.31	71.44	69.95	69.31
σ	(9.27)	(8.64)	(13.51)	(9.22)
Mean C.F.	13.83	13.33	13.67	14.17
σ	(6.45)	(5.50)	(4.07)	(4.58)

For runs 1 and 2 the increase in the mean % T.V. as the bar becomes closer to the fixation spot is significant at beyond the 0.01 level (Friedman Two-way analysis of Variance by Ranks X_r^2 = 12.1, d.f. = 3), while the mean C.F. appears to vary more or less randomly. However, for runs 3 and 4 the mean % T.V. and mean C.F. appear to remain more or less constant as the bar becomes closer to the fixation spot.

Therefore, from these two experiments one can conclude that there is a significant increase in mean percentage time visible of a line as it becomes closer to the central fixation spot. However, inter-subject differences are rather apparent, and there is evidence from the findings of runs 3 and 4 that, for some subjects, the phenomena under observation seem to habituate after a number of exposures to the same stimulus conditions, although this could not have been the case for the subject in the first experiment.

10.9. Vertical/Horizontal Parallel Line Interaction as a function of Foveal Placement

On the basis of the findings in section 6.4. on vertical parallel line interaction as a function of foveal placement, one might predict that subsequent experimentation would show the greater instability of the offset conditions relative to the equidistant condition, and that in the offset conditions, the inner of the two lines would be less stable than the outer. If the radial hypothesis of section 7.1.2. has any validity, and if this experiment were performed with the bars lying horizontally, then one would expect to find significantly greater instability of the lines under the offset conditions relative to the equidistant condition, and that, under the offset condition, the inner of the two lines would be less stable than the outer.

The present study utilized the same stimulus plates as the study on vertical parallel line interaction as a function of foveal placement, except that they were modified to allow them to be presented to study the horizontal as well as the vertical condition. A dental bite was again utilized to minimise head movements during fixation. The first trial of each run was a 'warm up' trial consisting of a 40 mm. parallel line test plate, the orientation being the same as that for the rest of the run. Initially the same student as in section 10.8. served as a subject and performed twenty-four runs comprising twelve runs with the stimulus configuration in the vertical plane and twelve runs with it in the horizontal plane, the order of presentation of the stimulus configurations conforming to a random block design. The obtained results were such that little, if any, use could be made of them as the subject appeared to rather quickly settle into a routine of indicating very few disappearances, and those which he did indicate were rather inconsistent, the results seeming to indicate a decided boredom with the rather repetitive series of runs (four runs/day).

In view of this, the same six students utilized in the previous study (section 10.8.) each performed four runs (no more than one run per day), two with the lines vertical and two with the lines horizontal. The experimental times were kept as near as possible to the same time of day for each subject in order to minimise any possible diurnal variation. The results are shown below, the parallel lines being either vertical and equidistant, 10 mm. to the right (R) or 10 mm. to the left (L); or horizontal and equidistant, 10 mm. above (A) or 10 mm. below (B).

Parallel Lines

	Vertical			Horizontal		
	Left	Equi-distant	Right	Above	Equi-distant	Below
Mean % Sim. T.V.	54.51 * a	62.08 * b	52.78	57.67	63.03	59.13
σ	(13.41)	(16.99)	(15.54)	(11.30)	(10.54)	(11.57)
Mean % Single T.V.	11.00 * c	6.83 * d	13.83	10.63	9.53	7.72
σ	(8.23)	(6.07)	(10.47)	(6.14)	(7.30)	(5.92)
Mean % Sim. C.F.	69.52 * e	81.13 * f	72.38	67.88	73.41	69.27
σ	(24.89)	(16.27)	(14.91)	(17.91)	(21.23)	(18.24)

	Vertical					
	Left		Equidistant		Right	
	L	R	L	R	L	R
Mean % T.V.	61.48	58.53	66.90	64.08	56.93	62.47
σ	(12.47)	(15.66)	(16.48)	(17.14)	(17.45)	(17.71)
Mean % T.V.	49.70	50.30	48.83	51.17	51.15	48.85
σ	(4.88)		(6.97)		(4.68)	

	Horizontal					
	Above		Equidistant		Below	
	B	T	B	T	B	T
Mean % T.V.	60.09 * g	65.87	68.12	67.46	63.93	62.05
σ	(11.64)	(9.38)	(10.27)	(10.31)	(12.80)	(12.63)
Mean % C.F.	51.57	48.43	50.77	49.23	47.03	52.97
σ	(5.78)		(5.09)		(6.05)	

* See overleaf.

* Wilcoxon Matched Pairs Signed Ranks Test ($N = 12$)

a) $T = 18$ $P = 0.05$ (one tailed)

b) $T = 15$ $P < 0.05$ (" ")

c) $T = 18$ $P = 0.05$ (" ")

d) $T = 8$ $P < 0.01$ (" ")

e) $T = 18$ $P = 0.05$ (" ")

f) $T = 18$ $P = 0.05$ (" ")

g) $T = 10$ $P = 0.02$ (two tailed)

It is worthwhile noting that although the results under the vertical condition revealed significant instability in the offset conditions relative to the equidistant condition, there was not significant confirmation of the original finding that, in the offset condition the inner of the two lines would be less stable than the outer. However, in view of the results giving six significant differences in the predicted direction for the vertical condition, there are reasonable grounds for considering the one significant difference found in the horizontal condition as being spurious. It would, therefore, seem reasonable to conclude that there is no significant instability under the horizontal offset conditions relative to the horizontal equidistant condition, and that the significant instability of the inner line relative to the outer in the horizontal 'above' condition was likely to be an artifact.

10.10. Two Vertical Parallel Lines with an Interposed 45° Diagonal

This particular study was done by the author using himself as the subject, an additional key, coupled to the pen recorder, being installed into the circuitry. Two stimulus configurations were used, both having two vertical parallel slots, with an interposed 45° diagonal slot, this being to the right in one and to the left in the other. All the slots were 30 x 2 mm., the central separation distance between the two verticals being 40 mm. The fixation 'spot' consisted of two 2 mm. diameter circular white spots placed on either side of the centre of the diagonal slot. The data for the two stimulus conditions were very similar and for simplicity have been grouped together for a one way analysis of variance of the major dimensions.

	Left Vert.	Diagonal	Right Vert.
Mean % Time Visible*	88.08	78.27	88.63
	(66.5)	(47.0)	(67.0)
σ	8.62	10.84	8.21

$S.E._{dM} = 2.74$ df = 2, 69 F = 9.047 $p < 0.001$

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* For comparison purposes, the percentage time visible for the three lines used in Tees' (1961) experiment, using a capital N, without the vertices, are shown in brackets.

	Left Vert.	Diagonal	Right Vert.
Mean % Change Frequency	31.01	39.21	29.78
σ	6.94	12.60	6.10

$S.E._{dM} = 2.66$ $df = 2, 69$ $F = 7.428$ $p < 0.005$*

	Left Vert.	Diagonal	Right Vert.
Mean Time from Flash to Last Disappearance**	89.85	79.74	89.90
σ	20.21	18.59	20.26

$S.E._{dM} = 5.81$

	Left Vert.	Diagonal	Right Vert.
Mean Time from Flash to First Disappearance**	43.02	37.93	43.43
σ	26.05	25.24	25.95

$S.E._{dM} = 7.59$

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* When the stricter form of testing was performed (which allowed for the much higher variance of the diagonal, compared with the two verticals), the level of significance was adjusted to $p = 0.05$.

** The value of the F ratio for these means was not significant.

10.11. Review of SRI and Related Literature from April 1967 - June 1969

Before considering the more recent findings relating to the consequences of stabilization, it is worth mentioning Riggs and Schick's (1968) counter to Barlow's (1963) findings on contact lens slippage. Riggs and Schick assert that Barlow made no attempt "to test the conventional type of stabilization equipment involving an external optical system and a plane mirror attached to the eye", p. 160. Utilizing this type of tightly fitting contact lens, and a vernier-offset method of aligning a stabilized image with an after-image, they found that the mean "moment to moment" slippage was about 0.32 min. arc while the median standard deviation during one minute runs was about 0.4 min. arc. They concluded that slippage of this magnitude is most unlikely to have any effect on the disappearance or reappearance of a SRI.

Moving on to the actual consequences of stabilization and in particular to the effects of flickering a SRI, West (1968) has reported a number of interesting findings, utilizing an optical lever system with a 1.5° bipartite field, flickering sinusoidally in the range 0-25 c/s. The percentage time for which this image was visible was found to reach a maximum at a certain frequency, f_p, and to fall off rapidly for frequencies on either side, f_p being a function of a number of parameters, such as luminance, field size, retinal location, percentage modulation, waveform and colour. However, when square wave flicker was used, multiple peaking occurred, and this was different for different colours (sinusoidal flicker, f_p did not appear to be a function of colour, as it was around 5 c/s, but anomalous results were obtained for a blue field). West considers that many of his results are consistent with the increase in size of retinal receptive fields as one moves out from the fovea, but many of the findings on f_p as a function of colour and waveform are thought to require considerably more investigation.

A number of recent findings are relevant to perceptual effects as a function of the degree and type of stabilization. Piggins (1968) has shown that 80% of a usable sample of 311 experimentally naive subjects reported fragmentation of a 4^o outline square when stabilized using a simple after-image technique. This is interesting in so far that most studies of SRI phenomena typically involve only a small number of sophisticated subjects. With regard to auditory stimulation being capable of regenerating a stabilized image which has disappeared (Pritchard and Vowles, 1960, as cited in Pritchard, Heron and Hebb, 1960), Wells and Evans (1968) have performed a related experiment concerning the effect of humming on a SRI which could not be displaced, relative to the retina, by mechanical vibration. Deploying the technique of flash after-imagery, they showed that the start of fragmentation of an after-image, a + inscribed in a circle, was temporally shortened relative to the no sound condition by hearing a 100 H_z tone, or by humming in tune with the tone while viewing.

Unfortunately no information was given relating to regeneration effects.

Further studies on brightness and colour discrimination have been reported by West (1967) using a bipartite field stabilized by an optical lever system. His findings were that the percentage of time for which the luminance difference was perceived was "(a) independent of field luminance; (b) increases with luminance difference; (c) increases with sharpness of boundary; (d) at first increases and then decreases as field size is increased; (e) decreases when the target is moved away from the centre of the visual field. White, red, green and yellow (minus blue) illumination give very similar results", p. 973. West concludes that the bulk of his findings can be accounted for on the basis of lateral inhibition in the visual system. He hypothesises that the range of this interaction is in the region of 2' in the central fovea for all colours apart from blue, which has a greater range of interaction, being in the region of 7', and this is thought to be due to the blue receptors being interconnected.

The organization of the breakdown of perception has been subjected to further investigation by some other recent studies. Monahan (1967) attempted a replication of Evans' (1965) findings that under SRI conditions, target visibility was a function of the smoothness of the figure, and also investigated the possibility of field effects. He used a simple flash after-image technique, but the results from his three subjects were somewhat inconsistent and therefore no useful conclusions could be drawn. Cardu and Gilbert (1967) have studied the type of disappearances found when different types of stabilized images (letters of the alphabet, regular and irregular polygons and full geometrical figures) are presented subtending different visual angles (30', 1° and 2°). The stabilizing system was very similar to Pritchard's (1961a) collimator system, and their results showed for the regular and irregular polygons and letters of the alphabet that, as the visual angle of the figures was increased, so the number of unitary fragmentations increased, while the number of total disappearances decreased, the number of irregular fragmentations showing no consistent change. For the solid geometrical figures, as their visual angle was increased the number of fragmentary disappearances increased, while the number of total disappearances by fading decreased, there being a very slight increase in the number of 'sudden' total disappearances. The authors interpret these findings as giving partial support to Hebb's theory of cell assemblies, under which Hebb (1963) has subsumed some of Hubel and Wiesel's (1962) findings on the receptive fields of cells in the striate cortex of the cat.

These findings by Cardu and Gilbert tie in reasonably well with the findings by Evans (1967) whose investigations, utilizing a more refined technique of flash after-image stabilization than used in earlier studies (i.e. Bennet-Clark and Evans, 1963), found evidence to suggest the existence of recognition units which could mediate in the perception of straight lines. This was done by studying the relationship between unitary and fragmentary disappearances of a vertical after-image (variable between 10' and 90' of arc) at different distances from the fovea (varying from 0° to 3°). The cross over points of the best fitting simple straight lines for the percentage unitary and fragmentary disappearances indicated that these recognition units varied from about 30' to 90' as one moves out from the fovea into the perifoveal regions. However, it is worth pointing out that there were marked individual differences in his findings, but they are suggestive of perceptual units in the human visual system, analogous to those found in cats and monkeys (i.e. Hubel and Wiesel, 1962, 1965, 1968).

Two papers concerned with binocular vision are worthy of brief mention. Smith (1968) has compared the 'structured' and 'unstructured' fragmentations of a + inscribed in a circle under the conditions of binocular rivalry with a Julesz random pattern and as a flash after-image SRI. His general finding was that for all ten subjects the 'structured' fragmentations were found to be considerably less frequent and less stable under the rivalry condition, and this was interpreted as supporting "the belief that the structured fragmentations reported in after-images and stabilized images depend on perceptual rather than response mechanisms", p. 276. Evans and Wells (1967) have investigated the fragmentation phenomena associated with binocular stabilization achieved using either a contact lens/collimator system or the technique of flash after-imagery. The results obtained when a simple stereo pair was presented as binocular after-images were somewhat equivocal, although the normal fused image was occasionally seen (however, stereoscopic depth perception of modified Julesz patterns has been obtained by Evans and Clegg (1967) using this technique of flash after-imagery). Evidence for central perceptual processing in stabilized fragmentation effects was found in the common reports of the unitary action of lines existing only in the fused image.

Finally reference should be made to investigations of EEG responses during stabilized vision. The study by Lehmann _et al_. (1965) using a contact lens/collimator stabilizing system and simultaneous EEG recording showed that subjective fade-out of the stabilized image (a 24° cross) was highly correlated with the occurrence of alpha trains, while periods when the image was visible were correlated with small amplitude fast activity. The temporal course of events was most revealing, as the onset of alpha activity occurred before fade-out of the SRI was reported, and, as the subject's motor reaction times were less than this difference in time, the authors concluded that "central processes control the time at which fluctuations of perception of a stabilized retinal image take place", p. 342 (substantially similar findings have been reported by Keesey and Nichols, 1967).

A subsequent study by Lehmann _et al_. (1967) showed that the above-mentioned cortical activity during periods of image visibility and fade-out were not apparent in the evoked responses to a 3.2/sec. light flashing in the other eye.

However, they did show that there was a greater reduction in the amplitude of these evoked potentials during the viewing of the target under normal vision than when stabilized, this being interpreted as indicating that, under normal viewing, a greater loading is placed on the higher levels of the visual system, than under stabilized conditions. A somewhat similar study by Riggs and Whittle (1967) used an optical lever stabilizing system and recorded occipital and retinal potentials to a striped pattern (subtending an angle of 6°, 40') which alternated (white/black) at the rate of 47.4 times/sec. The results indicated that there was no diminution in the retinal or occipital evoked potentials during periods of almost complete subjective disappearance of the stabilized image, even under a variety of stimulus conditions involving changes in frequency, intensity and wavelength. Similar findings were reported for evoked occipital potentials during suppression in binocular rivalry experiments. Riggs and Whittle point out that the lack of change in evoked cortical potentials under these conditions may well be due to the alpha activity, found by Lehmann et al. (1965), not being sufficiently well synchronized with the evoked potential waves and therefore not significantly increasing the size of the time-locked cumulated response.

ADDITIONAL REFERENCES

ANDREWS, D.P. (1967). Perception of contour orientation in the central fovea. Part 1: short lines. Vision Res., 7, 975-997.

CARDU, B., and GILBERT, M. (1967). Mode de disparition des figures stabilisées sous differents angles visuel. Canadian J. of Psychology, 21 (6), 526-534.

EVANS, C.R. (1967). Further studies of pattern perception and a stabilized retinal image: The use of prolonged after-images to achieve perfect stabilization. British J. of Psychology, 58 (3-4), 315-327.

EVANS, C.R., and CLEGG, J.M. (1967). Binocular depth perception of "Julesz patterns" viewed as perfectly stabilized retinal images. Nature, 215 (5103), 893-895.

EVANS, C.R., and WELLS, A.M. (1967). Fragmentation phenomena associated with binocular stabilisation. Brit. J. Physiol. Opt., 24, 45-50.

HUBEL, D.H., and WIESEL, T.N. (1968). Receptive fields and functional architecture of monkey striate cortex. J. Physiol., 195, 215-243.

KEESEY, U.T., and NICHOLS, D.J. (1967). Fluctuations in target visibility as related to the occurrence of the alpha component of the electroencephalogram. Vision Res., 7, 859-877.

LEHMANN, D., BEELER, G.W., and FENDER, D.H. (1965). Changes in patterns of the human electroencephalogram during fluctuations of perception of stabilized retinal images. Electroenceph. clin. Neurophysiol., 19, 336-343.

LEHMANN, W., BEELER, G.W., Jr., and FENDER, D.H. (1967). EEG responses to light flashes during the observation of stabilized and normal retinal images. Electroencephalography and Clinical Neurophysiology, 22 (2), 136-142.

MONAHAN, J. BETTIE (1967). The effect of stimulus form in disappearance phenomena in the visual afterimage. Papers in Psychology, 1(1), 32-33.

PIGGINS, D.J. (1968). Fragmentation of a prolonged, structured after-image viewed by naive observers. Amer. J. Psychol., 9, 282-288.

RIGGS, L.A., and SCHICK, A.M.L. (1968). Accuracy of retinal image stabilisation achieved with a plane mirror on a tightly fitting contact lens. Vision Res., 8, 159-169.

RIGGS, L.A., and WHITTLE, P. (1967). Human occipital and retinal potentials evoked by subjectively faded visual stimuli. Vision Res., 7, 441-451.

SMITH, P.K. (1968). Image fragmentations with afterimages and in binocular rivalry. Psychon. Sci., 10, 275-276.

WELLS, ANGELA M., and EVNAS, C.R. (1968). Effect of humming on the visibility of a stabilized retinal image. Nature, 217 (5134), 1168-1169.

WEST, D.C. (1967). Brightness discrimination with a stabilised retinal image. Vision Res., 7, 949-974.

WEST, D.C. (1968). Flicker and the stabilised retinal image. Vision Res., 8, 719-745.

ERRATA

Page 64: (Eysenck, 1964) should read (Eysenck and Eysenck, 1964a).

" 80: (Eysenck, 1964) should read (Eysenck and Eysenck, 1964b).

" 147: Omission of a reference after CLARKE, F.J.J., and BELCHER, S.J. (1962), etc., i.e. CLOWES, M.B. (1961). Some factors in brightness discrimination with constraint of retinal image movement. Optica Acta, 8, 81-91.

" 158: (Eysenck, 1964) should read (Eysenck and Eysenck, 1964b).